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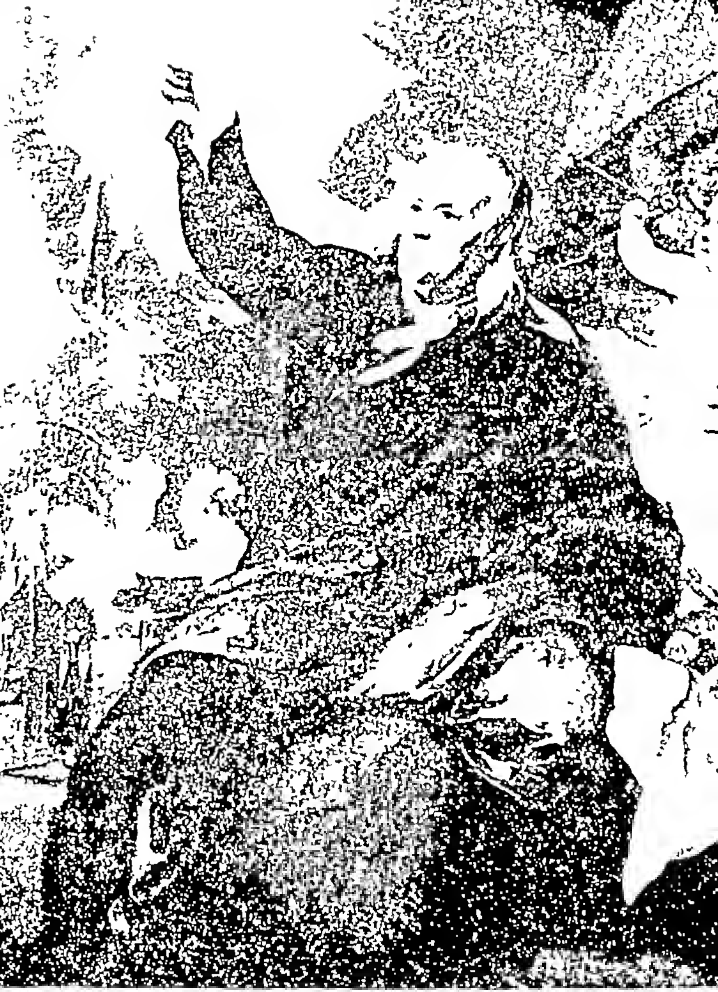
WONDER BOOK
OF THE
WORLD'S PROGRESS

VOL. VII

HISTORY • PEOPLES



FRANKLIN PLAYS WITH LIGHTNING

WONDER BOOK
OF THE
WORLD'S PROGRESS

By
HENRY SMITH WILLIAMS

IN TEN VOLUMES
Illustrated

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VOLUME VI
Inventions
Customs

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NEW YORK AND LONDON

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INVENTIONS • CUSTOMS

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INTRODUCTION

IN this volume we deal more directly with the mechanical inventions which are obviously associated with advances in practical civilization. We have elsewhere adverted to the advances made in prehistoric times, when, it has been suggested, far and away the most important discoveries were made. We now pass on to the activities of the historical period, and for the first time encounter names of individual discoverers. In presenting these names, however, one should bear always in mind that there is an element of unfairness in all historical records. The familiar cynicism that calls history "a tradition agreed upon" applies with full force to the history of a large number of scientific discoveries.

The point is that each discoverer builds upon the work of his predecessor, and that as a rule there are many workers who are searching the same or closely similar fields.

By and large, however, it may be taken for granted that the famous discoverers whose work will claim our attention justly earned their celebrity. They were indeed notable figures. "Every institution," says Emerson, "is the shadow of a great man " With rare exceptions, the men who are famed as great scientific discoverers are entitled to be called great. By this I mean that most of them were great in character as well as in intellectual accomplishments. There are notable exceptions, to be sure, but the rule holds

Our first concern, however, is not so much with the personality of the discoverer as with his accomplishment

Looking back, it will be fairly obvious that the scientific investigators in mechanical fields laid the foundation for the development of practical machinery. But we shall learn also that there is often a wide gulf between laboratory findings and the practicalities of the workshop. Human imagination does not reach very far beyond present observation; and conservatism—tendency to cling to the past—is the birthright of every ordinary man.

As to the manners and customs of our race, it scarcely needs saying that they are to a very large extent contingent on advances in the practicalities of humdrum civilization. The basic factors of agriculture, manufacture, and transportation determine very largely questions of housing, clothing, and manner of living of the individuals of any generation. Crude drawings of the cave-dwellers show women attired in costumes that differ not at all in their essentials from the costumes of the women of today. It has often been pointed out that the manner of life of the Oriental and the Classical nations differed very little from that of European nations of the eighteenth century. The changes that mark the nineteenth century were conditioned on the development of new machinery for agriculture, manufacture, and distribution, and new materials for its building of houses.

In telling the story of the development of the mechanisms that brought about this revolution, it will not be necessary to say much about the contingent changes in manners and customs of successive generations. But the pictorial presentation will serve as background, illustrating the changing fashions (and in particular contrasting the earlier with the more recent conditions) far better than words could tell the story. Here, as elsewhere in this series of books, the pictures must be regarded as an inherent part of the presentation.

I

MAN'S EARLY ACHIEVEMENTS

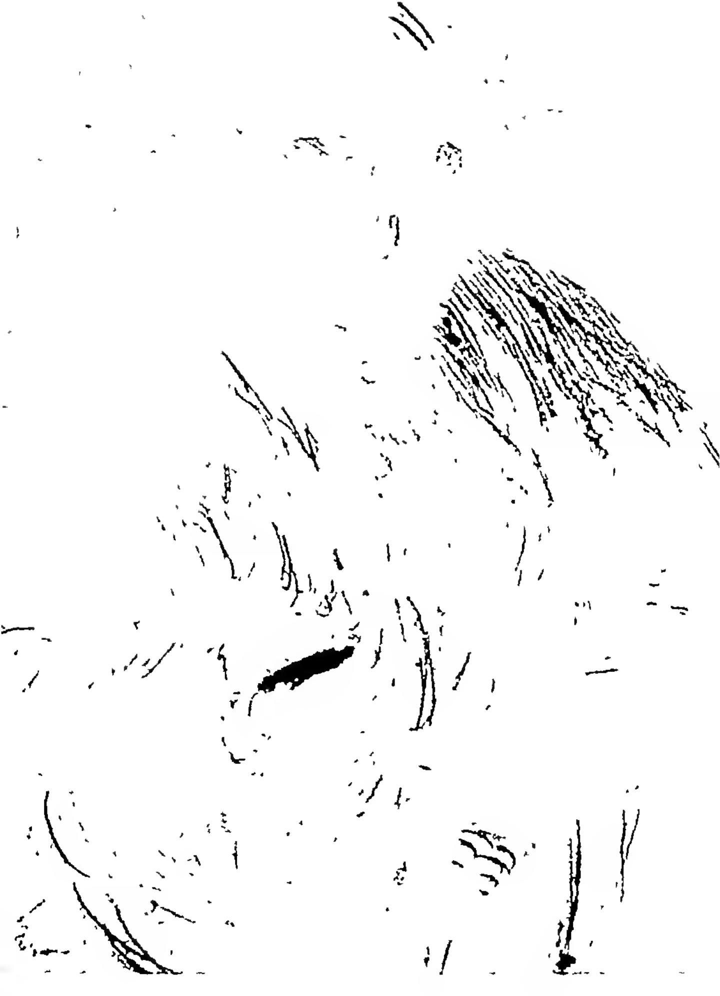
TO gain a clearer idea of the status of human culture at the dawn of history proper, let us glance in the most cursory way at certain of the great inventions and developments upon which the entire structure of civilization depends.

First—Language.

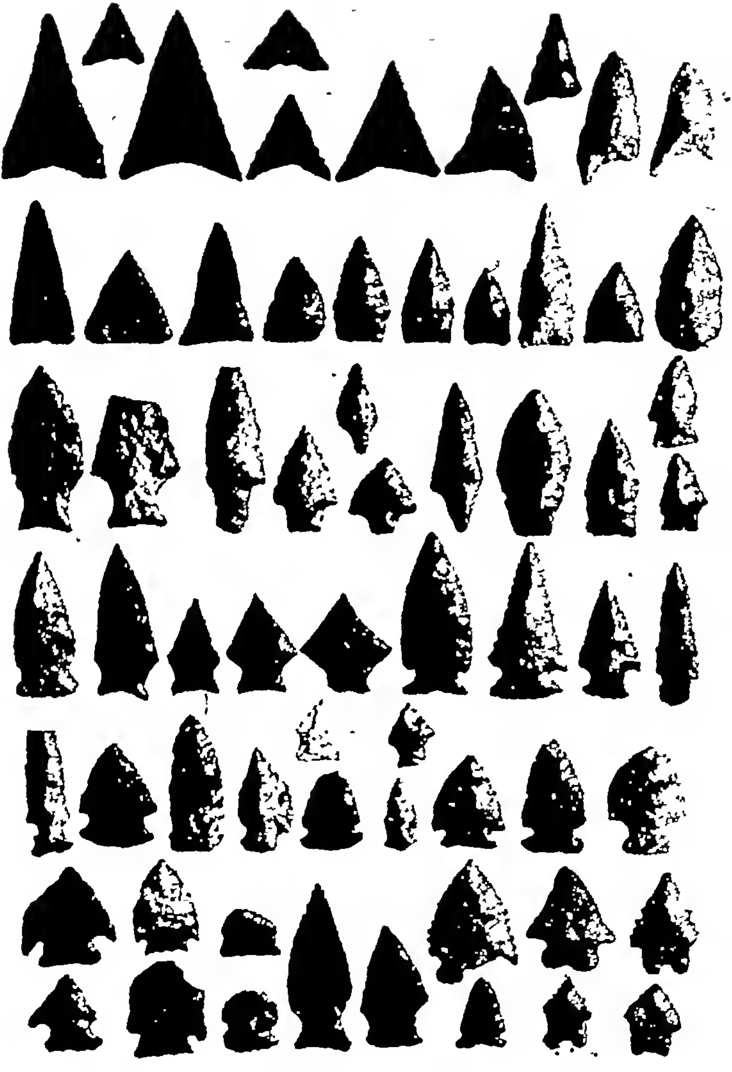
Perhaps the greatest single step ever made in the history of man's upward progress was taken when the practise of articulate speech began. It would be contrary to all that we know of human evolution to suppose that this development was a sudden one, or that it transformed a non-human into a human species at a sudden vault. It is well known that many of the lower animals are able to communicate with one another in a way that implies at least a vague form of speech, and it has been questioned whether the higher species of apes do not actually articulate in a way strictly comparable to the vocalization of man.

Be that as it may, the clear fact remains that one species of animal did at a very remote time in the past develop the power of vocalization in the direction of articulate speech to a degree that in course of time broadened the gap between that species and all others, till it became an impassable chasm.

Without language of an explicit kind not even the rudiments of civilization would be possible. No one perhaps ever epitomized the value of articulate speech



THE FIRST STONE CHIPPER



INDIAN ARROWHEADS

in a single phrase more tellingly than does Herder when he says: "The lyre of Amphion has not built cities. No magic wand has transformed deserts into gardens. Language has done it—that great source of sociality."

When the dawn of history proper came, man had so long practised speaking that he had developed countless languages so widely divergent from one another that they are easily classified into seven great types. From the study of these languages the philologist draws more or less valid inferences as to the later stages of linguistic growth and development. But he gains no inklings whatever as to any of those earlier developments which constituted the origin or the creation of language.

Second—Clothing and Housing of Prehistoric Man.

Nothing is more surprizing to the student of antiquity than to find at what seems the very beginning of civilization such monuments as the Pyramids and the great sculptures of Egypt and Mesopotamia.

But a moment's reflection makes it clear that man must have learned to house himself, as well as to clothe himself, before he can have started on that tour of conquest of the world which was so far advanced before the dawn of history.

Doubtless the original home of man must have been in a tropical or subtropical climate, and he cannot well have left these pampering regions until he had made a considerable development, almost the first step of which required that he should gain the means of protecting himself from the cold. The idea of such protection once acquired, its elaboration was but a question of time—and fashion.

Third—The Use of Fire.

Quite as fundamental as the matter of housing and clothing, and even more marvelous, considered as an

invention, was the recognition of the uses of fire, and the development of the methods of producing fire at will.

The use of fire must have been well known to the earliest generations of men that attempted to wander far from the tropics. Clothed, housed, and provided with fire, man was able to undertake the conquest of all regions, but without fire he dare not have braved the winters even of the middle latitudes, to say nothing of Arctic regions.

Probably the earliest method of producing fire practically employed was by friction of dry sticks, perhaps much after the manner still in use among certain savage tribes. Obviously the flint and steel, which for so many thousands of years was to be the sole practical means of producing fire among the civilized races, could not have come into vogue until the age of iron The "lucifer" match, which was finally to banish flint and steel, was an invention of the nineteenth century.

Fourth—Implements of Peace and War.

A gigantic bound was made when man first learned to use a club habitually, and doubtless the transition from a club to a mechanically pointed spear constituted a journey as long and as hard as the evolution from the spear to the modern repeating rifle.

But before the dawn of history there had been evolved from the club the battle-ax of metal, and from the crude spear the metal-pointed javelin, the arrow, the sword, and the dagger. The bow, too, of which the arrow was the complement, had long been perfected, and from it had evolved various other implements of warfare, culminating in the gigantic battering-ram.

Of implements of a more pacific character, boats of various types furnished means of transportation on the water, and wagons with wheel and axle, acting on precisely the principle still employed, had been perfected, both of these being used for purposes of war as well as in the arts of peace.

Manufacture necessarily included the making of materials for clothing, and this had advanced from the crude art of dressing skins to the weaving of woollen fabrics and fine linens that would bear comparison with the products of the modern loom.

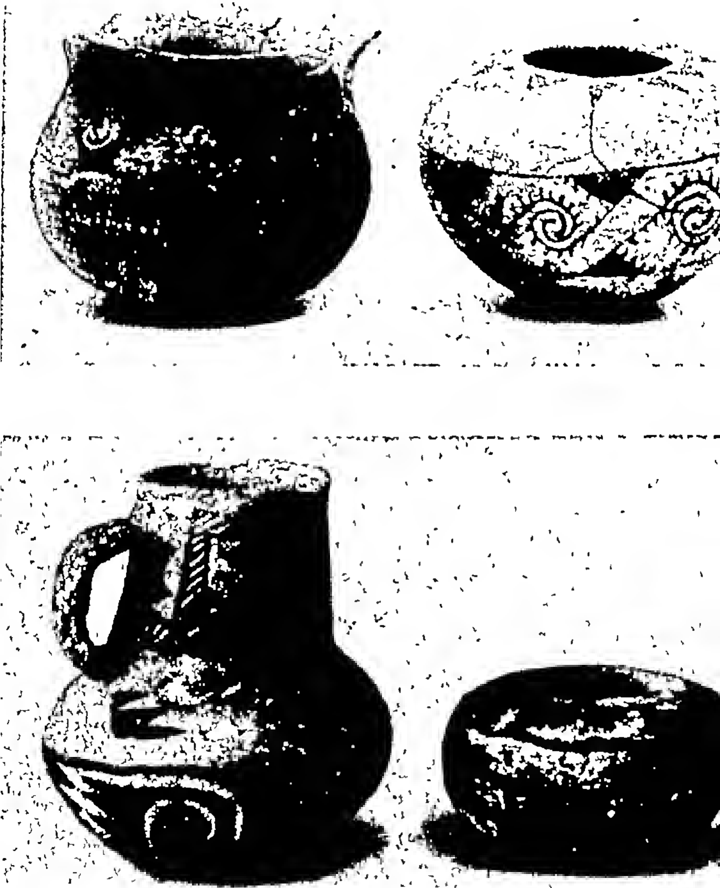
Stones were shaped and bricks made as materials for building. The principle of the pulley was well understood as an aid to human strength; and the potter's wheel, with which various household utensils were shaped, was absurdly like the ones that are still used for a like purpose.

In all these arts of manufacture, indeed, a degree of perfection had been attained in the prehistoric period upon which there was to be singularly little advance for some thousands of years. It was not until well toward the close of the eighteenth century that the series of great mechanical advances began with the application of steam to the propulsion of machinery, revolutionizing manufacture and for the first time radically changing the systems of transportation that were in vogue before the dawn of history; and it was only a few centuries earlier that the invention of gunpowder metamorphosed the methods of warfare that had been in vogue for a like period.

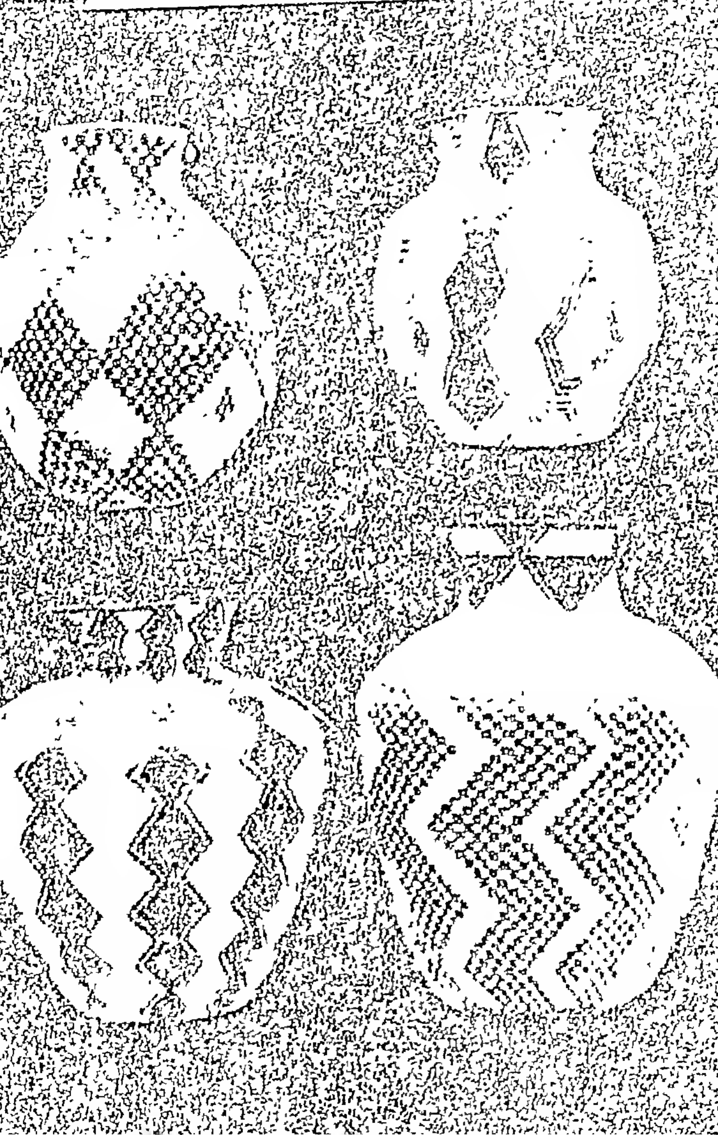
Fifth—The Domestication of Animals.

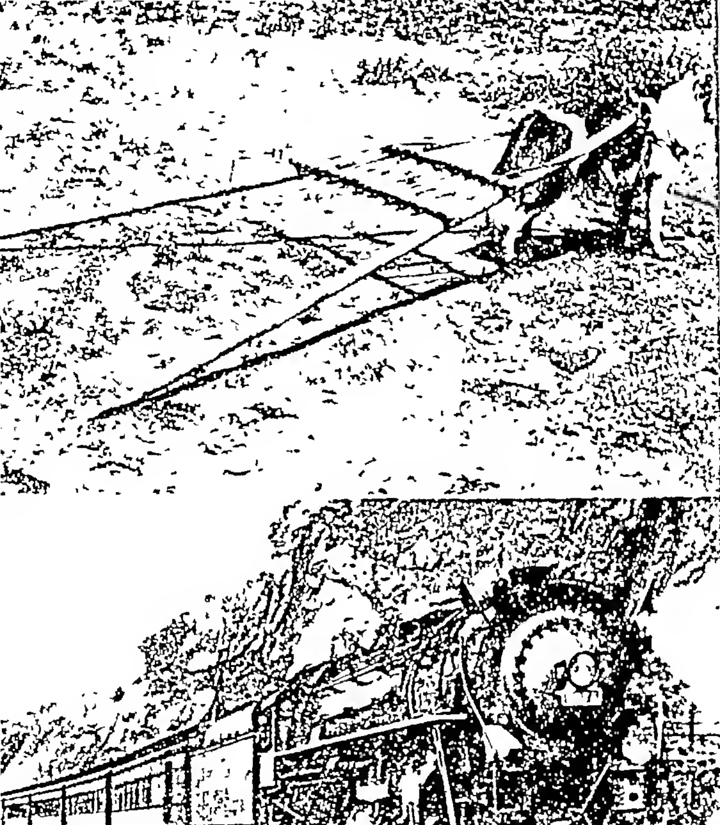
It is not difficult to imagine how revolutionary must have been the effect of the domestication of animals.

Primitive man can at first have had no idea of the possible utility of the animals about him, except as objects of pursuit; but doubtless at a very early stage it



PRIMITIVE POTTERY





TRANSPORTATION

became customary for children to tame, or attempt to tame, such animals as wolves, foxes, and cats of various tribes when taken young, much as children of today enjoy doing the same thing. This might readily lead to the early domestication or half-domestication of such animals as that species of wolf from which the various races of dogs sprang.

It is held that the dog was the first animal to become truly domesticated. Obviously this animal could be of advantage to man in the chase, even in very early stages of human evolution; and it is quite possible that a long series of generations may have elapsed before any animal was added to the list of man's companions.

But the great step was taken when herbivorous animals, useful not for the chase, but as supplying milk and flesh for food, were made tributary to the use of man.

From that day man was no longer a mere hunter and fisher; he became a herdsman, and in the fact of entering upon a pastoral life he had placed his foot firmly on the first rung of the ladder of civilization. An obvious change became necessary in the life of pastoral people. They could still remain nomads, to be sure, but their wanderings were restricted by a new factor. They must go where food could be found for their herds Moreover, economic features of vast importance were introduced in the fact that the herds of a people became a natural prey of less civilized peoples of the same region. It became necessary, therefore, to make provision for the protection of the herds, and in so doing an increased feeling of communal unity was necessarily engendered.

Hitherto, we may suppose, a single family might live by itself without greatly encountering interference from other families. So long as game was abundant and equally open to the pursuit of all, there would seem to be no reason why one family should systematically interfere with another, except in individual instances where quarrels of a strictly personal nature had arisen. But the pastoral life introduced an element of contention that must necessarily have led to the perpetual danger of warfare, and concomitantly to the growing necessity for such aggregate action on the part of numerous families as constituted the essentials of a primitive government.

It is curious to reflect on these two opposite results that must have grown almost directly from the introduction of the custom of domesticating food animals: on the one hand, the growth of the spirit of war between tribes; on the other, the development of the spirit of tribal unity, the germs of nationality.

Much thought has been given by naturalists to the exact origin of the various races of domesticated animals. Speaking in general terms, it may be said that Asia is the great original home of domesticated animals as a class.

Possibly the dog may be the descendant of some European wolf, and he had perhaps become the companion of man before that great hypothetical eastward migration of the "Aryans" took place, which the modern ethnologist believes to have preceded the Asiatic settlement of that race.

The cat also may not unlikely be a descendant of the European wildcat. But the sheep, the cow, the donkey, and the horse, as well as the barnyard fowl, are almost unquestionably of Asiatic origin.

Of these, the horse was probably the last to be domesticated, since we find that the Egyptians did not employ this animal until a relatively late stage of the historic period, namely, about the twentieth century B.C.

This does not mean that the horse was unknown to the Asiatic nations until so late a period, but it suggests a relatively recent use of this animal as compared, for example, with the use of cattle, which had been introduced into Egypt before the beginning of the historic period.

No animal of importance and only one bird—the turkey—has been added to the list of domesticated creatures since the dawn of history.

Sixth—Agriculture.

The studies of the philologists make it certain that long periods of time elapsed after man had entered on a pastoral life before he became an agriculturist. The proof of this is found, for example, in the fact that the Greeks and Romans use words obviously of the same derivation for the names of various domesticated animals while a similar uniformity does not pertain to their names for cultivated cereals or for implements of agriculture.

Theoretical consideration of the probable state of pastoral man would lead to the same conclusion. The gap between the wandering habits of the owners of flocks, whose chief care was to find pasture, and the fixed abode of an agricultural people, is indeed a wide one.

To be sure, the earliest agriculturist may not have been a strictly permanent resident of any particular district. He might migrate like the bird with the seasons, and change the region of his abode utterly from year to year. But he must in the nature of the case have remained in one place for several months together; that

A YOUNG INDIAN CHIEF

BEDOUIN OF EGYPT

is to say, from sowing to harvest time. To people of nomadic instincts this interference with their desires might be extremely irksome, to say nothing of the work involved in cultivating the soil.

But once the advantages of producing a vegetable food supply, according to a preconceived plan, instead of depending upon the precarious supply of nature, were fully understood and appreciated, another great forward movement had been made in the direction of ultimate civilization.

Incidentally it may be added that another incentive had been given one tribe to prey upon another; and, conversely, another motive for strengthening the bonds of tribal unity.

Agricultural plants, like domesticated animals, are largely of Asiatic origin. There are, however, four important exceptions, namely, maize among cereals, the two varieties of potato, and tobacco, all of which are indigenous to the western hemisphere, and hence were necessarily unknown to the civilized nations of antiquity. With these exceptions all the important agricultural plants had been known and cultivated for numberless generations before the opening of the historic period.

Seventh—Government.

We have just seen how the introduction of domesticated animals and agricultural plants must have influenced the communal habits of primitive man in the direction of the establishment of local government.

There are reasons to believe that, prior to taking these steps, the most advanced form of human settlement was the tribe or clan consisting of the members of a single family. The unit of this settlement was the single family itself with a man at its head, who was at once provider, protector, and master

As the various members of a family held together in obedience to the gregarious instinct, which man shares with the greater number of animals, it was natural that some one member of the clan should be looked to as the leader of the whole. In the ordinary course of events, such leader would be the oldest man, the founder of the original family. But there must have been a constant tendency for younger men of pronounced ability to aspire to the leadership, and to wrest from the patriarch his right of mastery.

Such mastery, however, whether held by right of age or of superior capacity, must have been in the early day very restricted in scope. Of necessity, primitive man depended largely on his own individual efforts both for securing food and for protection of himself and his immediate family against enemies. Under such circumstances an independence of character must have been developed that implies unwillingness to submit to the autocratic authority of another.

Only when the pastoral and agricultural phases of civilization had become fully established, would communities assume such numerical proportions as to bring the question of leadership of the clan into perpetual prominence; and no doubt a very long series of internal strifes and revolutionary dissensions must have preceded the final recognition of the fact that no large community can aspire to anything like integrity without the clear recognition of some centralized authority.

Under the conditions incident to the early stages of civilization, where man was subject to the marauding raids of enemies, it was but natural that this centralized authority should be conceded to some man whose recognized prowess in warfare had aroused the respect and admiration of his fellows.

FULL REGALIA

Thus arose the system of monarchial government, which we find fully established everywhere among the nations of antiquity when they first emerge out of the obscurity of the prehistoric period. The record of the slow steps of progress by which the rights of the individual came to strike an evener balance, as against the all-absorbing usurpations of the monarch and a small coterie of his adherents, constitute one of the chief elements of the story of later civilization. But when the story opens, there is scant intimation of this reaction. The monarch is all dominant; his individual subjects seem the mere puppets of his will.

Eighth—The Arts of Painting, Sculpture, and Decorative Architecture.

The graven fragments of ivory and of reindeer horn, found in the cave deposits of the Stone Age, give ample proof that man early developed the desire and the capacity for drawing

No doubt there was a more or less steady advance upon this art of the cave-dweller throughout succeeding generations, but the records of such progress are for the most part lost. The monuments of Egypt and of Mesopotamia, however, have been preserved to us in sufficient completeness to prove that the graphic arts had reached a really high stage of development before the close of the prehistoric period.

Rather curiously, the evolution of the graphic arts during the earlier centuries of the historic period was far more rapid than was that of the practical arts.

As early as the ninth century B.C. the Assyrians had developed the art of sculpture in bas-relief in a way that constituted a marvelous advance upon anything that may reasonably be believed to have been performed by prehistoric man, and only three centuries later came the culminating period of Greek art, which marked the stage of almost revolutionary progress.

Ninth—The Art of Writing.

One other art remains to be mentioned, even in the most cursory survey. This is the latest, and in some respects the greatest of them all—the art of writing.

In one sense this art is only a development of the art of drawing, but it is a development that had momentous consequences.

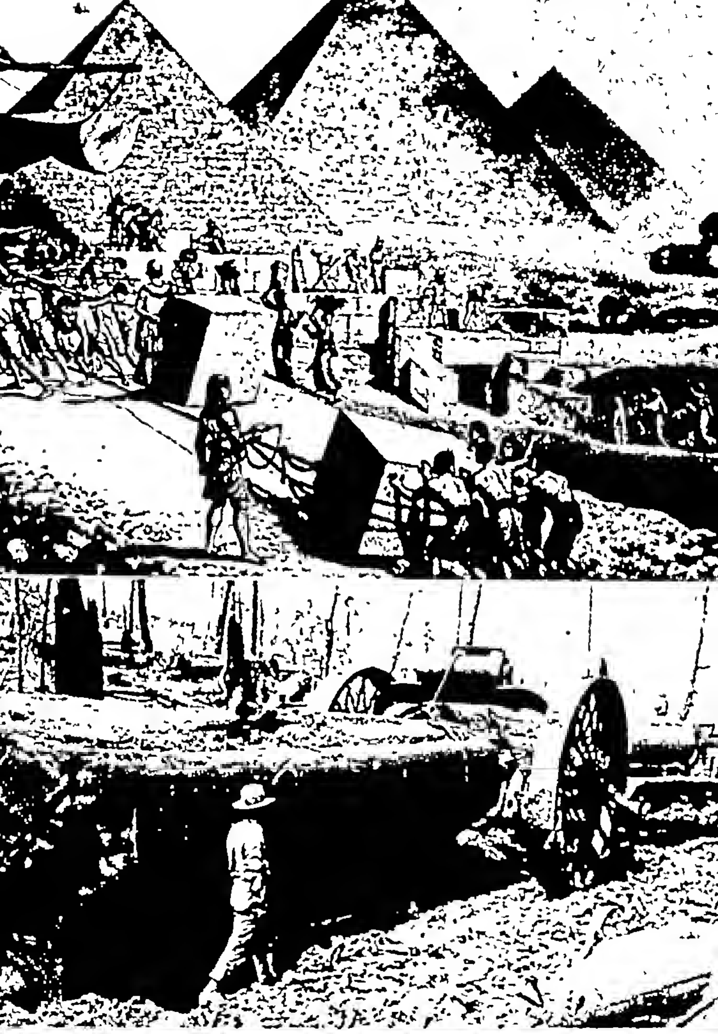
All the various phases of prehistoric culture at which we have just glanced have left reminiscences, more or less vague in character, for the guidance of students of later ages; but the materials for history proper began to be accumulated only after man had learned to give tangible expression to his thoughts in written words. No doubt the first steps toward this accomplishment were taken at a very early day.

We have seen that the cave-dweller even made graphic tho crude pictures, including hunting scenes, that are in effect the same in intent, and up to a certain point the same in result, as if the features of the event were described in words.

Doubtless there was no generation after the Stone Age in which men did not resort, more or less, to the graphic delineation of ideas.

A story that Herodotus, the "Father of History," tells of the message sent by the Scythians to Darius is significant. The Scythian messenger brought the body of a bird, a mouse, and a frog, together with a bundle of five arrows. Interrogated as to the meaning of this strange gift, the messenger replied that his instructions were to present the objects and retire.

Darius and his officers were much puzzled to interpret the message, Darius himself being disposed to



HEAVY TRANSPORTATION THEN AND NOW

regard it as an admission on the part of the Scythians that they conceded him lord of their territory, the land, water, and air; but one of the officers of the great king gave a different interpretation, which was presently accepted as the correct one. As he read the message it implied that unless the Persians could learn to fly through the air like birds, or to burrow through the earth like a mouse, or to dive through the water like a frog, they should not be able to escape the arrows of the Scythians.

Miss Amelia B. Edwards, in her delightful book on Egypt, raises a question as to the exact way in which the bird and mouse and frog and arrows were presented to Darius. She suggests that they were fastened to a piece of bark, or perhaps to a fragment of hide, in fixed position, so that they became virtually hieroglyphics. The question is interesting, but of no vital importance, since the exact manner of presentation would not in any way alter the intent, but would only bear upon the readiness of its interpretation.

The real point of interest lies in the fact of this transmission of ideas by symbols, which constitutes the essence of the art of writing.

It may be presumed that crude methods of sending messages, not unlike this of the Scythians, were practised more or less independently, and with greater or less degrees of elaboration, by barbaric and half-civilized tribes everywhere. The familiar case of the American Indians, who were wont to send a belt of wampum and an arrow as a declaration of war, is an illustration in point.

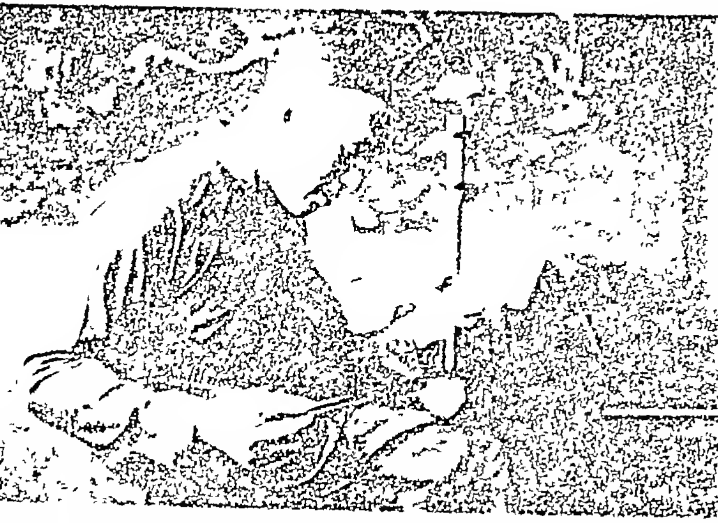
The gap between such a presentation of tangible objects and the use of crude pictures to replace the objects themselves would not seem, from a civilized standpoint, to be a very wide one. Yet no doubt it was an enormously difficult gap to cross. Granted the idea, any one could string together the frog, the bird, the mouse, and the arrows, but only here and there a man would possess the artistic skill requisite to make fairly recognizable pictures of these objects.

It is true that the cave-man of a vastly earlier period had developed a capacity to draw the outlines of such animals as the reindeer and the mammoth with astonishing verisimilitude. Professor Sayce has drawn the conclusion from this that the average man dwelling in the caves of France at that remote epoch could draw as well as the average Frenchman of today. But a moment's consideration will make it clear that the facts in hand by no means warrant so sweeping a conclusion. There is nothing to show, nor is there any reason to believe, that the cave-dweller pictures that have come down to us are the work of average men of that period. On the contrary, it is much more likely that they were the work, not of average men, but of the artistic geniuses of their day—of the Michelangelos and Rembrandts, or, if you prefer, the Landseers and Bonheurs, of their time.

There is no more reason to suppose that the average cave-dwellers could have drawn the reindeer hunting scene or the famous picture of the mammoth, than that the average Frenchman of today could have painted the Horse Fair.

There is no reason then to suppose that the average Scythian could have made himself equally intelligible to Darius by drawing pictures instead of sending actual objects, tho quite possibly there were some men among the Scythian hordes who could have done so.

The idea of such pictorial ideographs had seemingly



not yet come to the Scythians, but that idea had been attained many centuries before by other people of a higher plane of civilization. At least four thousand years before the age of Darius, the Babylonians, over whose descendants the Persian king was to rule, had invented or developed a picture-writing and elaborated it until it was able to convey, not merely vague generalities, but exquisite shades of meaning.

The Egyptians, too, at a period probably at least as remote, had developed what seems an independent system of picture-writing, and brought it to an astonishing degree of perfection.

At least three other systems of picture-writing in elaborated forms are recognized, namely, that used by the Hittites in Western Asia, that of the Chinese, and that of the Mexican Indians in America. No dates can be fixed as to when these were introduced, neither is it possible to demonstrate the entire independence of the various systems; but all of them were developed in prehistoric periods.

There seems no reason to doubt that in each case the picture-writing consisted originally of the mere graphic presentation of an object as representing an idea connected with that object itself, precisely as if the Scythians had drawn pictures of the mouse, the bird, the frog, and the arrows in order to convey the message to Darius.

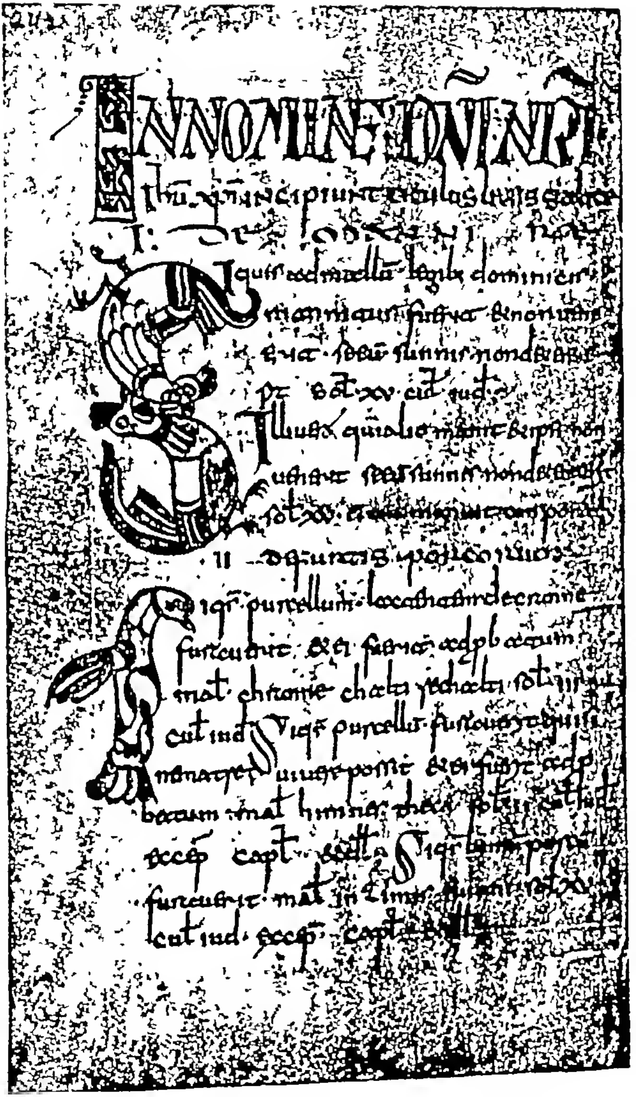
Doubtless periods of incalculable length elapsed after the use of such ideograms as this had come into vogue before the next great step was taken, which consisted in using a picture, not merely to represent some idea associated with the object depicted, but to represent a sound.

Probably the first steps of this development came about through the attempt to depict the names of men. Since the name of a man is often a combination of syllables having no independent significance, it was obviously difficult to represent that name in a picture record; and yet, in the nature of the case, the name of the man might often constitute the most important part of the record. Sooner or later the difficulty was met, as the Egyptian hieroglyphics prove to us, by adopting a system of phonetics, in which a certain picture stands for the sound of each syllable of the name. The pictures selected for such syllabic use were usually chosen because the name of the object presented by the picture began with the sound in question. Such a syllabary having been introduced, its obvious utility led presently to its application, not merely to the spelling of proper names, but to general purposes of writing.

One other step remained, namely, to make that final analysis of sounds which reduces the multitude of syllables to about twenty-five elementary sounds, so that the entire cumbersome structure of ideographs and syllables might be dispensed with. The Egyptians made this analysis before the dawn of history, and had provided themselves with an alphabet; but, strangely enough, they had not given up—nor did they ever relinquish in subsequent times—the system of ideographs and syllabics that mark the stages of evolution of the alphabet.

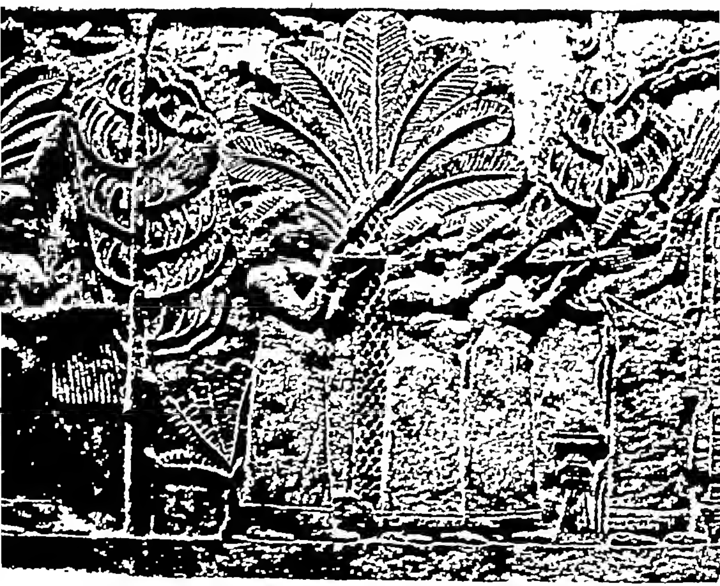
The Babylonians at the beginning of their historic period had developed a most elaborate system of syllabics, but their writing had not reached the alphabet stage.

The introduction of the alphabet to the exclusion of the cruder methods was a feat accomplished within the historic period by the Phenicians. This feat is justly regarded as one of the greatest accomplishments of the

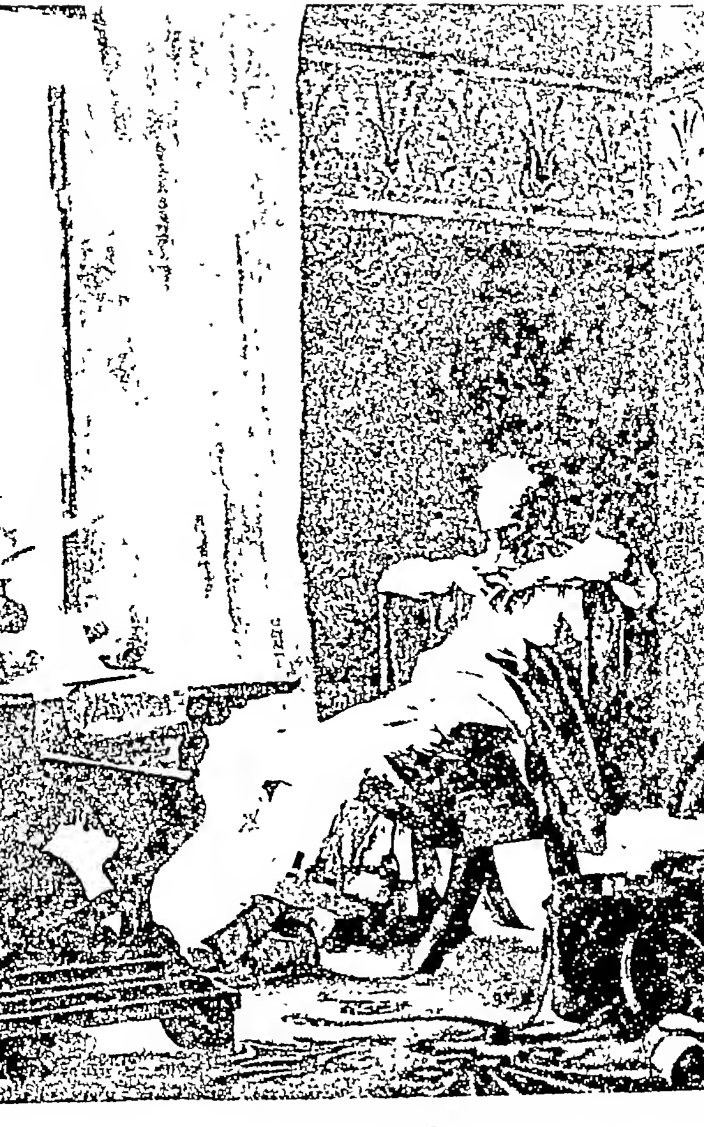


LEX SALICA (A.D. 794)

entire historic period. But that estimate must not blind us to the fact that the Egyptians and Babylonians, and probably also the Chinese, were in possession of their fully elaborated systems of writing long before the very beginnings of the historic period. Indeed, as has been said, true history could not begin until individual human deeds began to be recorded in written words.



BABYLONIAN RECORDS



ARCHIMEDES

II

ARCHIMEDES AND THE FOUNDATION OF MECHANICS

WE enter now upon the most important scientific epoch of antiquity. When Aristotle and Theophrastus passed from the scene, Athens ceased to be in any sense the scientific center of the world. That city still retained its reminiscent glory, and cannot be ignored in the history of culture, but no great scientific leader was ever again to be born or to take up his permanent abode within the confines of Greece proper.

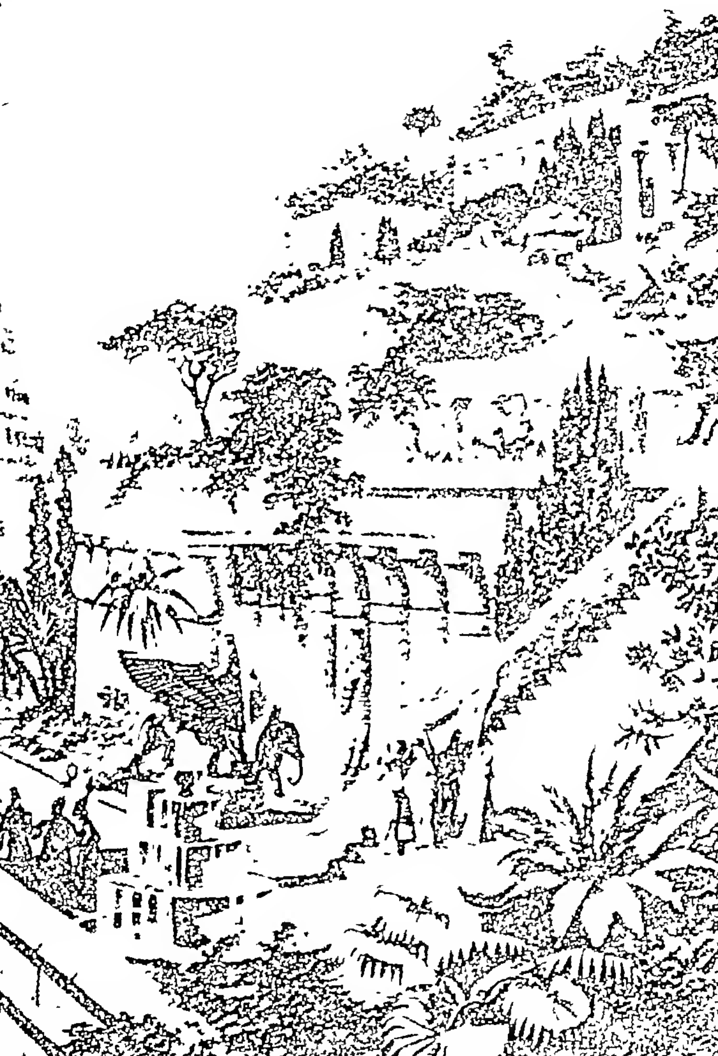
With almost cataclysmic suddenness, a new intellectual center appeared on the south shore of the Mediterranean. This was Alexandria, a city which Alexander the Great had founded during his brief visit to Egypt, and which became the capital of Ptolemy Soter when he chose Egypt as his portion of the dismembered empire of the great Macedonian. Ptolemy had been with his master in the East, and was with him in Babylonia when he died. He had therefore come personally in contact with Babylonian civilization, and we cannot doubt that this had a most important influence upon his life, and through him upon the new civilization of the West.

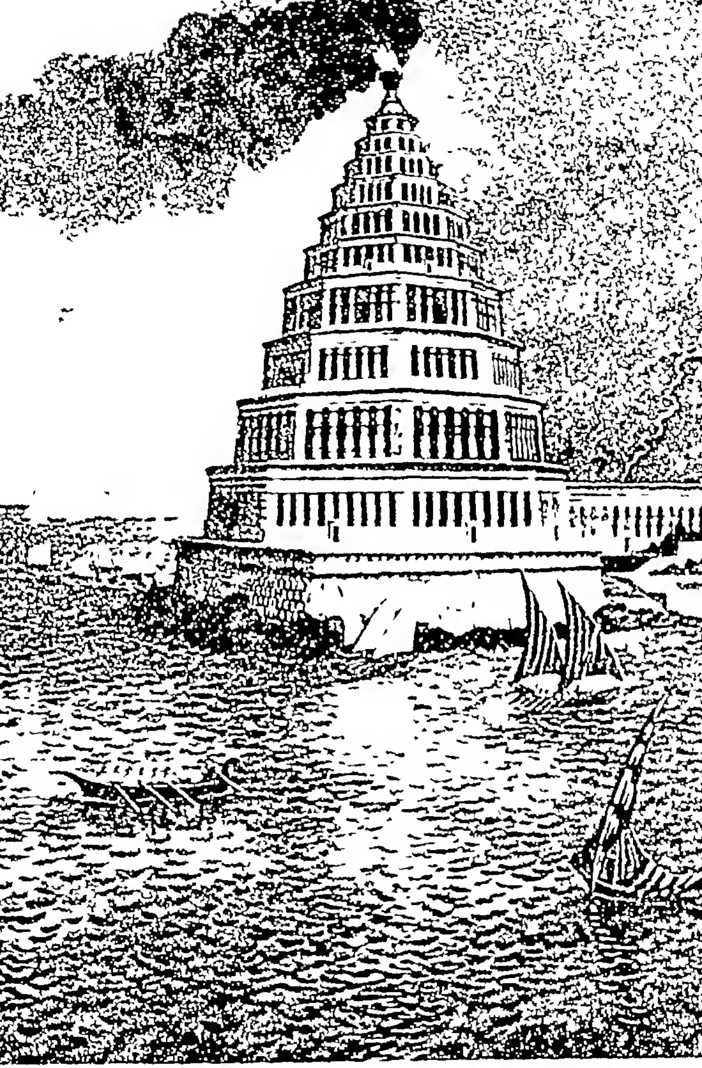
In point of culture, Alexandria must be regarded as the successor of Babylon, scarcely less directly than of Greece. Following the Babylonian model, Ptolemy erected a great museum and began collecting a library. Before his death it was said that he had collected no fewer than two hundred thousand manuscripts. He had gathered also a company of great teachers and founded a school of science which, as has just been said, made Alexandria the culture-center of the world.

Athens in the day of her prime had known nothing quite like this. Such private citizens as Aristotle are known to have had libraries, but there were no great public collections of books in Athens, or in any other part of the Greek domain, until Ptolemy founded his famous library. Such libraries had existed in Babylonia for thousands of years.

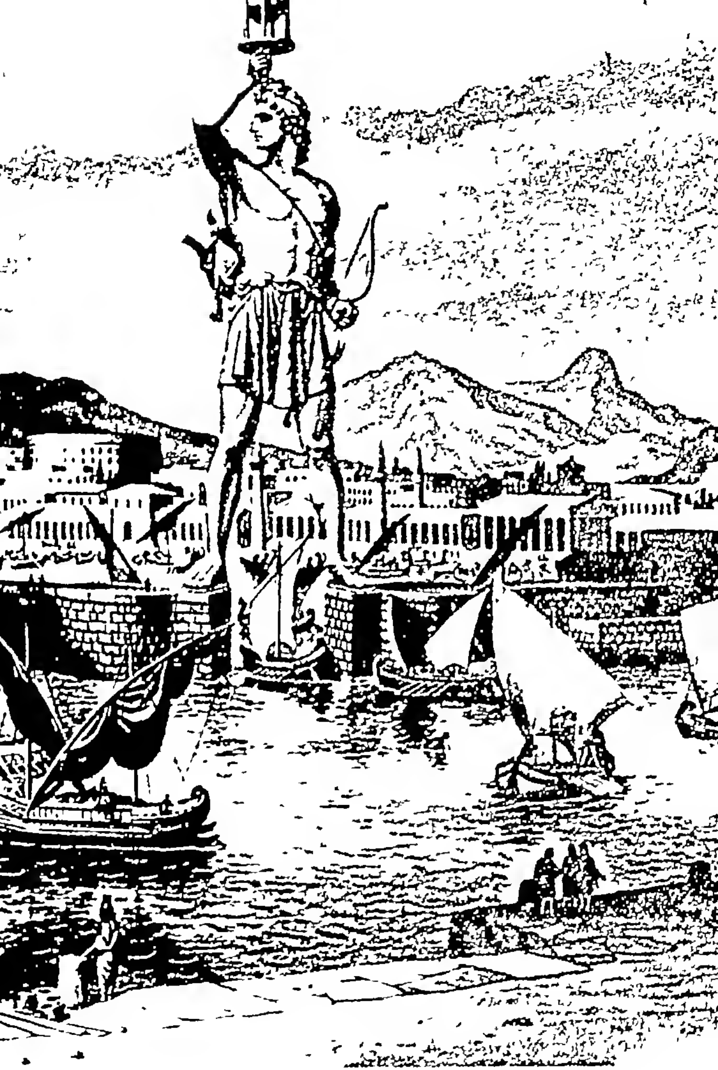
The character which the Ptolemaic epoch took on was no doubt due to Babylonian influence, but quite as much to the personal experience of Ptolemy himself as an explorer in the Far East. The marvelous conquering journey of Alexander had enormously widened the horizon of the Greek geographer, and stimulated the imagination of all ranks of the people. It was but natural, then, that geography and its parent science astronomy should occupy the attention of the best minds in this succeeding epoch. In point of fact, such a company of star-gazers and earth-measurers came upon the scene in this third century B.C. as had never before existed anywhere in the world.

The whole trend of the time was toward mechanics. It was as if the greatest thinkers had squarely faced about from the attitude of the mystical philosophers of the preceding century, and had set themselves the task of solving all the mechanical riddles of the universe. They no longer troubled themselves about problems of "being" and "becoming"; they gave but little heed to metaphysical subtleties; they demanded that their thoughts should be gaged by objective realities Hence there arose a succession of great geometers, and their





THE PHAROS OF ALEXANDRIA



THE COLOSSUS AT RHODES

conceptions were applied to the construction of new mechanical contrivances on the one hand, and of new theories of sidereal mechanics on the other.

The wonderful company of men who performed the feats that are about to be recorded did not all find their home in Alexandria, to be sure; but they all came more or less under the Alexandrian influence. We shall see that there are two other important centers; one out in Sicily, almost at the confines of the Greek territory in the west; the other in Asia Minor, notably on the island of Samos—the island which, it will be recalled, was at an earlier day the birthplace of Pythagoras.

But whereas in the previous century colonists from the confines of the civilized world came to Athens, now all eyes turned toward Alexandria, and so improved were the facilities for communication that no doubt the discoveries of one coterie of workers were known to all the others much more quickly than had ever been possible before We learn, for example, that the studies of Aristarchus of Samos were definitely known to Archimedes of Syracuse, out in Sicily. Indeed, as we shall see, it is through a chance reference preserved in one of the writings of Archimedes that one of the most important speculations of Aristarchus is made known to us.

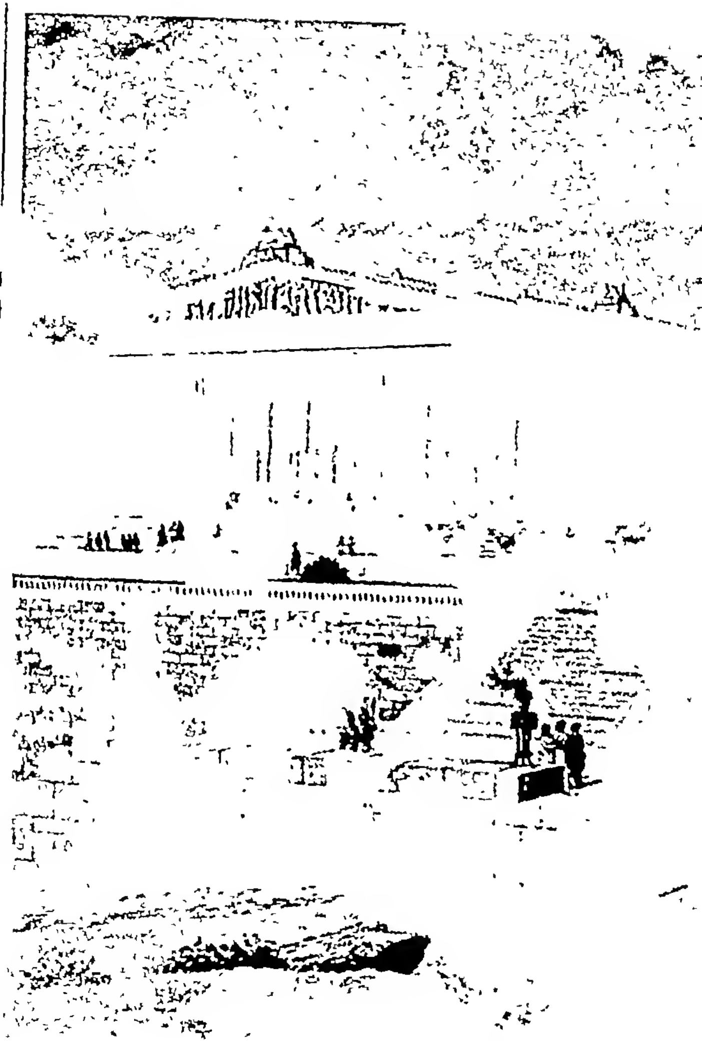
This illustrates sufficiently the intercommunication through which the thought of the Alexandrian epoch was brought into a single channel. We no longer, as in the day of the earlier schools of Greek philosophy, have isolated groups of thinkers. The scientific drama is now played out upon a single stage; and if we pass, as we shall in the present chapter, from Alexandria to Syracuse and from Syracuse to Samos, the shift of scenes does no violence to the dramatic unities.

Notwithstanding the number of great workers who were not properly Alexandrians, the epoch is with propriety termed Alexandrian. Not merely in the third century B.C., but throughout the lapse of at least four succeeding centuries, the city of Alexander and the Ptolemies continued to hold its place as the undisputed culture-center of the world. During that period Rome rose to its pinnacle of glory and began to decline, without ever challenging the intellectual supremacy of the Egyptian city.

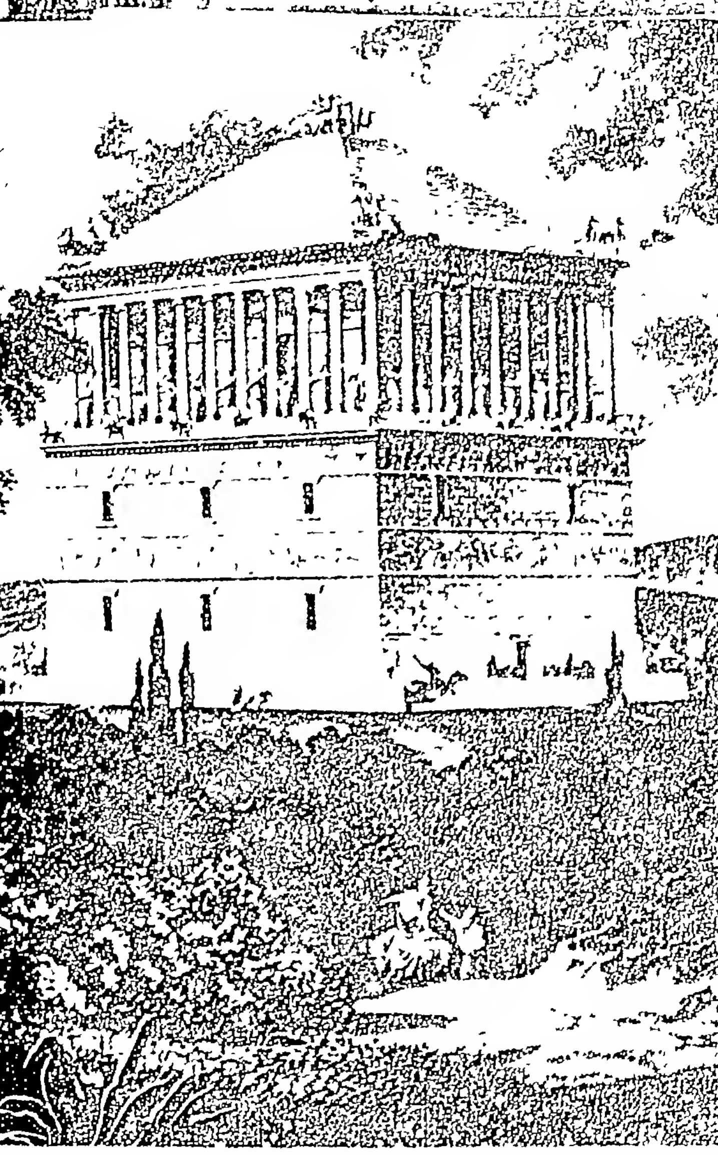
The Alexandrian influences were passed on to the Mohammedan conquerors, and when Alexandria was finally overthrown its place was taken by another Greek city, Byzantium or Constantinople. But that transfer did not occur until Alexandria had enjoyed a longer period of supremacy as an intellectual center than had perhaps ever before been granted to any city, with the possible exception of Babylon.

Our present concern is with that first wonderful development of scientific activity which began under the first Ptolemy, and which presents, in the course of the first century of Alexandrian influence, the most remarkable coterie of scientific workers and thinkers that antiquity produced. The earliest group of these new leaders in science had at its head a man whose name has been a household word ever since. This was Euclid, the father of systematic geometry.

Tradition has preserved to us but little of the personality of this remarkable teacher; but, on the other hand, his most important work has come down to us in its entirety. The *Elements of Geometry*, with which the name of Euclid is associated in the mind of every school-boy, presented the chief propositions of its subject in so simple and logical a form that the work



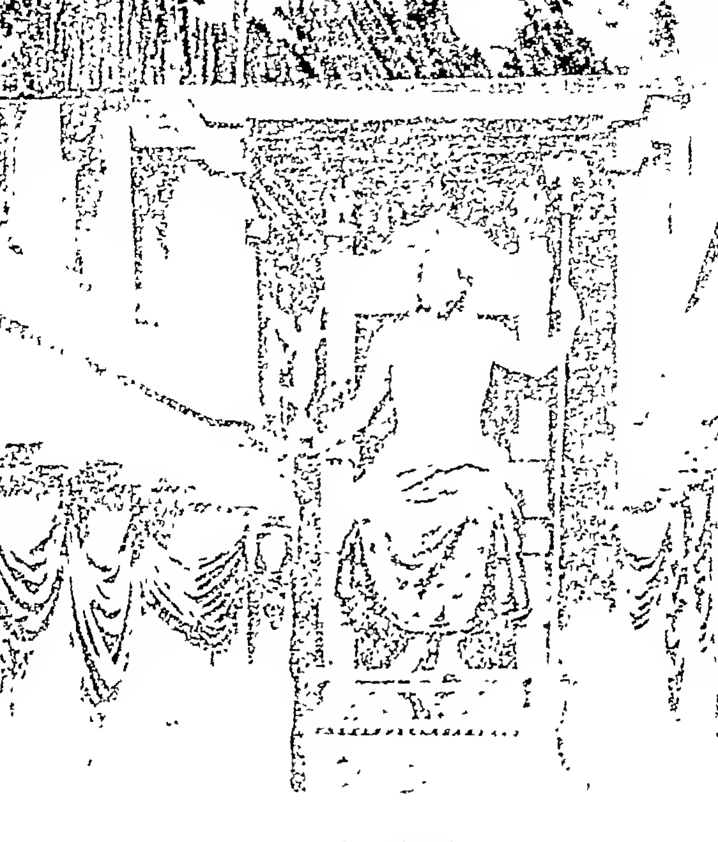
TEMPLE OF DIANA AT EPHESUS



remained a textbook everywhere for more than two thousand years.

Euclid's work, of course, gives expression to much knowledge that did not originate with him. We have already seen that several important propositions of geometry had been developed by Thales, and one by Pythagoras, and that the rudiments of the subject were at least as old as Egyptian civilization. Precisely how much Euclid added through his own investigations cannot be ascertained. It seems probable that he was a diffuser of knowledge rather than an originator, but as a great teacher his fame is secure. He is credited with an epigram which in itself might insure him perpetuity of fame: "There is no royal road to geometry," was his answer to Ptolemy when that ruler had questioned whether the *Elements* might not be simplified. Doubtless this, like most similar good sayings, is apocryphal; but whoever invented it has made the world his debtor.

We do not know just when Euclid died, but as he was at the height of his fame in the time of Ptolemy I., whose reign ended in the year 285 B.C., it is hardly probable that he was still living when a young man named Archimedes came to Alexandria to study. Archimedes was born in the Greek colony of Syracuse, on the island of Sicily, in the year 287 B.C. When he visited Alexandria he probably found Apollonius of Perga, the pupil of Euclid, at the head of the mathematical school there. Just how long Archimedes remained at Alexandria is not known. When he had satisfied his curiosity or completed his studies, he returned to Syracuse and spent his life there, chiefly under the patronage of King Hiero, who seems fully to have appreciated his abilities.



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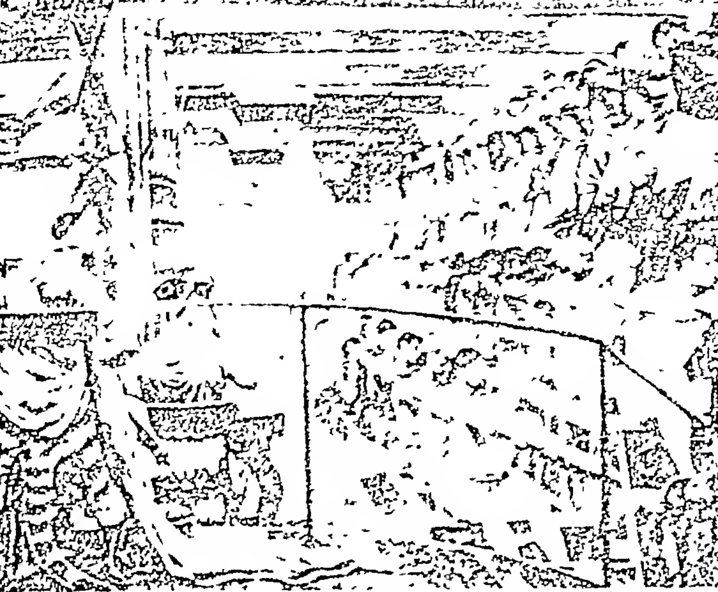
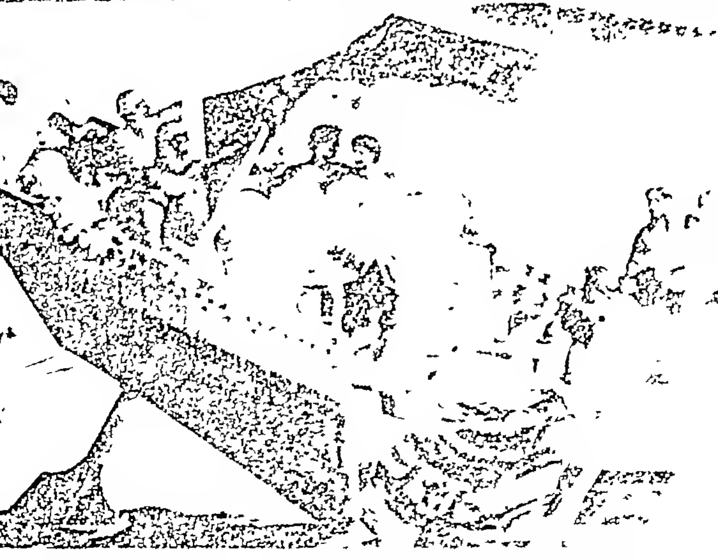
Archimedes was primarily a mathematician. Left to his own devices, he would probably have devoted his entire time to the study of geometrical problems. But King Hiero had discovered that his protégé had wonderful mechanical ingenuity, and he made good use of this discovery.

Under stress of the king's urgings, the philosopher was led to invent a great variety of mechanical contrivances, some of them most curious ones. Antiquity credited him with the invention of more than forty machines, and it is these, rather than his purely mathematical discoveries, that gave his name popular vogue both among his contemporaries and with posterity.

Every one has heard of the screw of Archimedes, through which the paradoxical effect was produced of making water seem to flow up hill. The best idea of this curious mechanism is obtained if one will take in hand an ordinary corkscrew, and imagine this instrument to be changed into a hollow tube, retaining precisely the same shape but increased to some feet in length and to a proportionate diameter. If one will hold the corkscrew in a slanting direction and turn it slowly to the right, supposing that the point dips up a portion of water each time it revolves, one can in imagination follow the flow of that portion of water from spiral to spiral, the water always running downward, of course, yet paradoxically being lifted higher and higher toward the base of the corkscrew, until finally it pours out (in the actual Archimedes' tube) at the top. There is another form of the screw in which a revolving spiral blade operates within a cylinder, but the principle is precisely the same. With either form water may be lifted, by the mere turning of the screw, to any desired height. The ingenious mechanism excited the wonder





of the contemporaries of Archimedes, as well it might. More efficient devices have superseded it in modern times, but it still excites the admiration of all who examine it, and its effects seem as paradoxical as ever.

Some other of the mechanisms of Archimedes have been made known to successive generations of readers through the pages of Polybius and Plutarch. These are the devices through which Archimedes aided King Hiero to ward off the attacks of the Roman general Marcellus, who in the course of the second Punic war laid siege to Syracuse.

Plutarch, in his life of Marcellus, describes the Roman's attack and Archimedes' defense in much detail. Incidentally he tells us how Archimedes came to make the devices that rendered the siege so famous:

"Marcellus himself, with threescore galleys of five rowers at every bank, well armed and full of all sorts of artillery and fireworks, did assault by sea, and rowed hard to the wall, having made a great engine and device of battery, upon eight galleys chained together, to batter the wall: trusting in the great multitude of his engines of battery, and to all such other necessary provision as he had for wars, as also in his own reputation. But Archimedes made light account of all his devices, as indeed they were nothing comparable to the engines he himself had invented.

"Archimedes having told King Hiero, his kinsman and friend, that it was possible to remove as great a weight as he would, with as little strength as he listed to put to it: and boasting himself thus (as they report of him) and trusting to the force of his reasons, wherewith he proved this conclusion, that if there were another globe of earth, he was able to remove this of ours, and pass it over to the other: King Hiero wondering to hear him, required him to put his device in execution, and to make him see by experience, some great or heavy weight removed, by little force.

"So Archimedes caught hold with a hook of one of the greatest carects, or hulks of the king (that to draw it to the shore out of the water required a marvelous number of people to go about it, and was hardly to be done so) and put a great number of men more into her, than her ordinary burden: and he himself sitting alone at his ease far off, without any straining at all, drawing the end of an engine with many wheels and pulleys, fair and softly with his hand, made it come as gently and smoothly to him, as it had floated in the sea.

"The king wondering to see the sight, and knowing by proof the greatness of his art; he prayed him to make him some engines, both to assault and defend, in all manner of sieges and assaults. So Archimedes made him many engines, but King Hiero never occupied any of them, because he reigned the most part of his time in peace without any wars. But this provision and munition of engines, served the Syracusans' turn marvelously at that time: and not only the provision of the engines ready made, but also the engineer and workmaster himself, that had invented them.

"Now the Syracusans, seeing themselves assaulted by the Romans, both by sea and by land, were marvelously perplexed, and could not tell what to say, they were so afraid: imagining it was impossible for them to withstand so great an army. But when Archimedes fell to handling his engines, and to set them at liberty, there flew in the air infinite kinds of shot, and marvelous great stones, with an incredible noise and force on the sudden, upon the footmen that came to assault the city by land, bearing down and tearing in pieces all those which came against them, or in what place soever they lighted, no earthly body being able to resist the violence of so heavy a weight: so that all their ranks were marvelously disordered.

"And as for the galleys that gave assault by sea, some were sunk with long pieces of timber like unto the yards of ships, whereto they fasten their sails, which were suddenly blown over the walls with force of their engines into their galleys, and so sunk them by their over great weight."

Polybius describes what was perhaps the most important of these contrivances, which was, he tells us, "a hand of iron, hanging by a chain from the beak of a machine, which was used in the following manner. The person who, like a pilot, guided the beak, having let fall the hand, and catched hold of the prow of any vessel, drew down the opposite end of the machine that was on the inside of the walls. And when the vessel was thus raised erect upon its stern, the machine itself was held immovable; but, the chain being suddenly loosened from the beak by the means of pulleys, some of the vessels were thrown upon their sides, others turned with the bottom upwards; and the greatest part, as the prows were plunged from a considerable height into the sea, were filled with water, and all that were on board thrown into tumult and disorder.

"Marcellus was in no small degree embarrassed," Polybius continues, "when he found himself encountered in every attempt by such resistance. He perceived that all his efforts were defeated with loss; and were even derided by the enemy. But, amidst all the anxiety that he suffered, he could not help jesting upon the inventions of Archimedes. This man, said he, employs our ships as buckets to draw water: and boxing about our sackbuts, as if they were unworthy to be associated with him, drives them from his company with disgrace. Such was the success of the siege on the side of the sea."

Subsequently, however, Marcellus took the city by strategy, and Archimedes was killed, contrary, it is said, to the express orders of Marcellus. "Syracuse being taken," says Plutarch, "nothing grieved Marcellus more than the loss of Archimedes. Who, being in his study when the city was taken, busily seeking out by himself the demonstration of some geometrical proposition which he had drawn in figure, and so earnestly occupied therein, as he neither saw nor heard any noise of enemies that ran up and down the city, and much less knew it was taken: he wondered when he saw a soldier by him, that bade him go with him to Marcellus. Notwithstanding, he spake to the soldier, and bade him tarry until he had done his conclusion, and brought it to demonstration: but the soldier being angry with his answer, drew out his sword and killed him.

"Others say, that the Roman soldier, when he came, offered the sword's point to him, to kill him: and that Archimedes when he saw him, prayed him to hold his hand a little, that he might not leave the matter he looked for imperfect, without demonstration. But the soldier making no reckoning of his speculation, killed him presently. It is reported a third way also, saying that certain soldiers met him in the streets going to Marcellus, carrying certain mathematical instruments in a little pretty coffer, as dials for the sun, spheres, and angles, wherewith they measure the greatness of the body of the sun by view: and they supposing he had carried some gold or silver, or other precious jewels in that little coffer, slew him for it.

MURDER OF ARCHIMEDES

"But it is most certain that Marcellus was marvelously sorry for his death, and ever after hated the villain that slew him, as a cursed and execrable person: and how he had made also marvelous much afterwards of Archimedes' kinsmen for his sake."

We are further indebted to Plutarch for a summary of the character and influence of Archimedes, and for an interesting suggestion as to the estimate which the great philosopher put upon the relative importance of his own discoveries.

"Notwithstanding Archimedes had such a great mind, and was so profoundly learned, having hidden in him the only treasure and secrets of geometrical inventions: as he would never set forth any book how to make all these warlike engines, which won him at that time the fame and glory, not of man's knowledge, but rather of divine wisdom. But he esteeming all kind of handicraft and invention to make engines, and generally all manner of sciences bringing common commodity by the use of them, to be but vile, beggarly, and mercenary dross: employed his wit and study only to write things, the beauty and subtlety whereof were not mingled anything at all with necessity.

"For all that he hath written, are geometrical propositions, which are without comparison of any other writings whatsoever: because the subject whereof they treat, doth appear by demonstration, the maker gives them the grace and the greatness, and the demonstration proving it so exquisitely, with wonderful reason and facility, as it is not repugnable. For in all geometry are not to be found more profound and difficult matters written, in more plain and simple terms, and by more easy principles, than those which he hath invented. Now some do impute this, to the sharpness of his wit and understanding, which was a natural gift in him: others do refer it to the extreme pains he took, which made these things come so easily from him, that they seemed as if they had been no trouble to him at all."

It should be observed that neither Polybius nor Plutarch mentions the use of burning-glasses in connection with the siege of Syracuse, nor indeed are these referred to by any other ancient writer of authority. Nevertheless, a story gained credence down to a late day to the effect that Archimedes had set fire to the fleet of the enemy with the aid of concave mirrors. An experiment was made by Sir Isaac Newton to show the possibility of a phenomenon so well in accord with the genius of Archimedes, but the silence of all the early authorities makes it more than doubtful whether any such expedient was really adopted.

It will be observed that the chief principle involved in all these mechanisms was a capacity to transmit great power through levers and pulleys, and this brings us to the most important field of the Syracusan philosopher's activity. It was as a student of the lever and the pulley that Archimedes was led to some of his greatest mechanical discoveries. He is even credited with being the discoverer of the compound pulley. More likely he was its developer only, since the principle of the pulley was known to the old Babylonians, as their sculptures testify. But there is no reason to doubt the general outlines of the story that Archimedes astounded King Hiero by proving that, with the aid of multiple pulleys, the strength of one man could suffice to drag the largest ship from its moorings.

The property of the lever, from its fundamental principle, was studied by him, beginning with the self-evident fact that "equal bodies at the ends of the equal

THE SEVENTH WONDER IS STILL WONDERFUL

arms of a rod, supported on its middle point, will balance each other;" or, what amounts to the same thing stated in another way, a regular cylinder of uniform matter will balance at its middle point. From this starting-point he elaborated the subject on such clear and satisfactory principles that they stand today practically unchanged and with few additions.

From all his studies and experiments he finally formulated the principle that "bodies will be in equilibrio when their distance from the fulcrum or point of support is inversely as their weight." He is credited with having summed up his estimate of the capabilities of the lever with the well-known expression, "Give me a fulcrum on which to rest or a place on which to stand, and I will move the earth."

But perhaps the feat of all others that most appealed to the imagination of his contemporaries, and possibly also the one that had the greatest bearing upon the position of Archimedes as a scientific discoverer, was the one made familiar through the tale of the crown of Hiero. This crown, so the story goes, was supposed to be made of solid gold, but King Hiero for some reason suspected the honesty of the jeweler, and desired to know if Archimedes could devise a way of testing the question without injuring the crown. Greek imagination seldom spoiled a story in the telling, and in this case the tale was allowed to take on the most picturesque of phases.

The philosopher, we are assured, pondered the problem for a long time without succeeding, but one day as he stepped into a bath, his attention was attracted by the overflow of water. A new train of ideas was started in his ever-receptive brain. Wild with enthusiasm he sprang from the bath, and, forgetting his robe, dashed along the streets of Syracuse, shouting: "Eureka! Eureka!" (I have found it!)

The thought that had come into his mind was this: That any heavy substance must have a bulk proportionate to its weight; that gold and silver differ in weight, bulk for bulk, and that the way to test the bulk of such an irregular object as a crown was to immerse it in water. The experiment was made. A lump of pure gold of the weight of the crown was immersed in a certain receptacle filled with water, and the overflow noted. Then a lump of pure silver of the same weight was similarly immersed; lastly the crown itself was immersed, and of course—for the story must not lack its dramatic sequel—was found bulkier than its weight of pure gold. Thus the genius that could balk warriors and armies could also foil the wiles of the silversmith.

Whatever the truth of this picturesque narrative the fact remains that such experiments as these must have paved the way for perhaps the greatest of all the studies of Archimedes—those that relate to the buoyancy of water. Leaving the field of fable, we must now examine these with some precision. Fortunately, the writings of Archimedes himself are still extant, in which the results of his remarkable experiments are related, so we may present the results in the words of the discoverer. Here they are:

"First: The surface of every coherent liquid in a state of rest is spherical, and the center of the sphere coincides with the center of the earth. Second: A solid body which, bulk for bulk, is of the same weight as a liquid, if immersed in the liquid will sink so that the surface of the body is even with the surface of the liquid, but will not sink deeper. Third: Any solid body which is lighter, bulk for bulk, than a liquid, if placed in the liquid will sink so deep as to displace the mass of liquid equal in weight to another body. Fourth: If a body which is lighter than a liquid is forcibly immersed in the liquid, it will be pressed upward with a force corresponding to the weight of a like volume of water, less the weight of the body itself. Fifth: Solid bodies which, bulk for bulk, are heavier than a liquid, when immersed in the liquid sink to the bottom, but become in the liquid as much lighter as the weight of the displaced water itself differs from the weight of the solid."

These propositions are not difficult to demonstrate, once they are conceived, but their discovery, combined with the discovery of the laws of statics already referred to, may justly be considered as proving Archimedes the most inventive experimenter of antiquity.

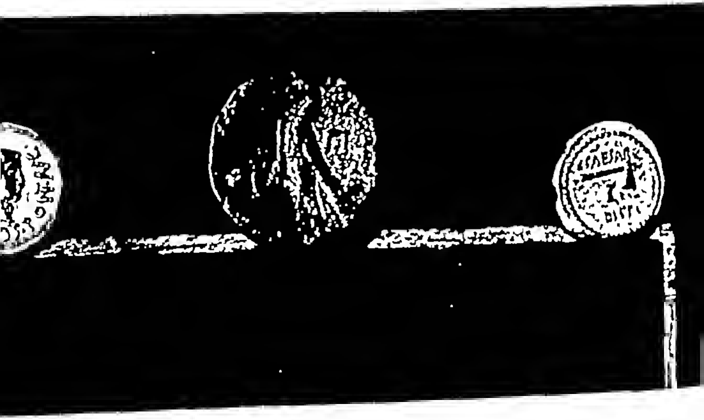
Curiously enough, the discovery which Archimedes himself is said to have considered the most important of all his innovations is one that seems much less striking. It is the answer to the question, What is the relation in bulk between a sphere and its circumscribing cylinder? Archimedes finds that the ratio is simply two to three. We are not informed as to how he reached his conclusion, but an obvious method would be to immerse a ball in a cylindrical cup. The experiment is one which any one can make for himself, with approximate accuracy, with the aid of a tumbler and a solid rubber ball or a billiard-ball of just the right size.

Another geometrical problem which Archimedes solved was the problem as to the size of a triangle which has equal area with a circle; the answer being, a triangle having for its base the circumference of the circle and for its altitude the radius. Archimedes solved also the problem of the relation of the diameter of the circle to its circumference; his answer being a close approximation to the familiar 3.1416, which every tyro in geometry will recall as the equivalent of π.

Numerous other of the studies of Archimedes having reference to conic sections, properties of curves and spirals, and the like, are too technical to be detailed here. The extent of his mathematical knowledge, however, is suggested by the fact that he computed in great detail the number of grains of sand that would be required to cover the sphere of the sun's orbit, making certain hypothetical assumptions as to the size of the earth and the distance of the sun for the purposes of argument. Mathematicians find his computation peculiarly interesting because it evidences a crude conception of the idea of logarithms.

We need not follow Archimedes to the limits of his incomprehensible numbers of sand-grains. The calculation is chiefly remarkable because it was made before the introduction of the so-called Arabic numerals had simplified mathematical calculations. It will be recalled that the Greeks used letters for numerals, and, having no cipher, they soon found themselves in difficulties when large numbers were involved. The Roman system of numerals simplified the matter somewhat, but the beautiful simplicity of the decimal system did not come into vogue until the Middle Ages, as we shall see. Notwithstanding the difficulties, however, Archimedes followed out his calculations to the piling up of bewildering numbers, which the modern mathematician finds to be the consistent outcome of the problem he had set himself.

But it remains to notice the most interesting feature of this document in which the calculation of the sand-grains is contained. "It was known to me," says Archimedes, "that most astronomers understand by the expression 'world' (universe) a ball of which the center is the middle point of the earth, and of which the radius is a straight line between the center of the earth and the sun." Archimedes himself appears to accept this opinion of the majority—it at least serves as well as the contrary hypothesis for the purpose of his calculation—but he goes on to say: "Aristarchus of Samos, in his writing against the astronomers, seeks to establish the fact that the world is really very different from this. He holds the opinion that the fixed stars and the sun are immovable and that the earth revolves in a circular line about the sun, the sun being at the center of this circle." This remarkable bit of testimony establishes beyond question the position of Aristarchus of Samos as the Copernicus of antiquity. We must make further inquiry as to the teachings of the man who had gained such a remarkable insight into the true system of the heavens



ROMAN COINS

III

ARISTARCHUS OF SAMOS, THE COPERNICUS OF ANTIQUITY

IT appears that Aristarchus was a contemporary of Archimedes, but the exact dates of his life are not known. He was actively engaged in making astronomical observations in Samos somewhat before the middle of the third century B.C.; in other words, just at the time when the activities of the Alexandrian school were at their height. Hipparchus, at a later day, was enabled to compare his own observations with those made by Aristarchus, and, as we have just seen, his work was well known to so distant a contemporary as Archimedes. Yet the facts of his life are almost a blank for us, and of his writings only a single one has been preserved. That one, however, is a most important and interesting paper on the measurements of the sun and the moon. Unfortunately, this paper gives us no direct clue as to the opinions of Aristarchus concerning the relative positions of the earth and sun. But the testimony of Archimedes on that point is unequivocal, and this testimony is supported by other rumors in themselves less authoritative.

In contemplating this astronomer of Samos, then, we are in the presence of a man who had solved in its essentials the problem of the mechanism of the solar system. It appears from the words of Archimedes that Aristarchus had propounded his theory in explicit writings. Unquestionably, then, he held to it as a positive doctrine, not as a mere vague guess. We shall show, in a moment, on what grounds he based his opinion.

Had his teaching found vogue, the story of science would be very different from what it is. We should then have no tale to tell of a Copernicus coming upon the scene fully seventeen hundred years later with the revolutionary doctrine that our world is not the center of the universe. We should not have to tell of the persecution of a Bruno or of a Galileo for teaching this doctrine in the seventeenth century of an era which did not begin till two hundred years after the death of Aristarchus. But, as we know, the teaching of the astronomer of Samos did not win its way. The old conservative geocentric doctrine, seemingly so much more in accordance with the every-day observations of mankind, supported by the majority of astronomers with the Peripatetic philosophers at their head, held its place. It found fresh supporters presently among the later Alexandrians, and so fully eclipsed the heliocentric view that we should scarcely know that view had even found an advocate were it not for here and there such a chance record as the phrases we have just quoted from Archimedes. Yet, as we now see, the heliocentric doctrine, which we know to be true, had been thought out and advocated as the correct theory of celestial mechanics by at least one worker of the third century B.C.

Fully to understand the theory of Aristarchus, we must go back a century or two and recall that as long ago as the time of that other great native of Samos, Pythagoras, the conception had been reached that the earth is in motion. While all the other philosophers, so far as we know, still believed that the world was flat, the Pythagoreans out in Italy taught that the world is a sphere and that the apparent motions of the heavenly bodies are really due to the actual motion of the earth itself.

They did not, however, vault to the conclusion that this true motion of the earth take places in the form of a circuit about the sun. Instead of that, they conceived the central body of the universe to be a great fire, invisible from the earth, because the inhabited side of the terrestrial ball was turned away from it. The sun, it was held, is but a great mirror, which reflects the light from the central fire. Sun and earth alike revolve about this great fire, each in its own orbit. Between the earth and the central fire there was, curiously enough, supposed to be an invisible earthlike body which was given the name of Anticthon, or counter-earth. This body, itself revolving about the central fire, was supposed to shut off the central light now and again from the sun or from the moon, and thus to account for certain eclipses for which the shadow of the earth did not seem responsible. It was, perhaps, largely to account for such eclipses that the counter-earth was invented. But it is supposed that there was another reason.

The Pythagoreans held that there is a peculiar sacredness in the number ten. Just as the Babylonians of the early day and the Hegelian philosophers of a more recent epoch saw a sacred connection between the number seven and the number of planetary bodies, so the Pythagoreans thought that the universe must be arranged in accordance with the number ten. Their count of the heavenly bodies, including the sphere of the fixed stars, seemed to show nine, and the counter-earth supplied the missing body.

The precise genesis and development of this idea cannot now be followed, but that it was prevalent about the fifth century B.C. as a Pythagorean doctrine cannot be questioned. The evidence, so far as we can garner it from remaining fragments, tends to show that all along, from the time of the early Pythagoreans, there had been an undercurrent of opinion in the philosophical world which questioned the fixity of the earth; and it would seem that the school of thinkers who tended to accept the revolutionary view centered in Asia Minor, not far from the early home of the founder of the Pythagorean doctrines. It was not strange, then, that the man who was finally to carry these new opinions to their logical conclusion should hail from Samos.

But what was the support which observation could give to this new, strange conception that the heavenly bodies do not in reality move as they seem to move, but that their apparent motion is due to the actual revolution of the earth?

It is extremely difficult for any one nowadays to put himself in a mental position to answer this question. We are so accustomed to conceive the solar system as we know it to be, that we are wont to forget how very different it is from what it seems. Yet we need only glance up at the sky, and then back to the solid earth, to grant, on a moment's reflection, that the geocentric idea is of all others the most natural; and that to conceive the sun as the actual center of the solar system is an idea which must look for support to some other evidence than that which ordinary observation can give.

What, then, was the line of scientific induction that led Aristarchus to this wonderful goal? Fortunately, we are able to answer that query, at least in part. Aristarchus gained his evidence through some wonderful measurements.

First, he measured the disks of the sun and the moon. This, of course, could in itself give him no clue to the distance of these bodies, and therefore no clue as to their relative size; but in attempting to obtain such a clue he hit upon a wonderful yet altogether simple experiment. It occurred to him that when the moon is precisely dichotomized—that is to say, precisely at the half—the line of vision from the earth to the moon must be precisely at right-angles with the line of light passing from the sun to the moon. At this moment, then, the imaginary lines joining the sun, the moon, and the earth, make a right-angled triangle. But the properties of the right-angled triangle had long been studied and were well understood. One acute angle of such a triangle determines the figure of the triangle itself.

Thales, the very earliest of the Greek philosophers, measured the distance of a ship at sea by the application of this principle. Now Aristarchus sights the sun in place of Thales' ship, and, sighting the moon at the same time, measures the angle and establishes the shape of his right-angled triangle. This does not tell him the distance of the sun, to be sure, for he does not know the length of his base-line—that is to say, of the line between the moon and the earth. But it does establish the relation of that base-line to the other lines of the triangle; in other words, it tells him the distance of the sun in terms of the moon's distance.

As Aristarchus strikes the angle, it shows that the sun is eighteen times as distant as the moon. Now, by comparing the apparent size of the sun with the apparent size of the moon—which, as we have seen, Aristarchus has already measured—he is able to tell us that the sun is "more than 5832 times, and less than 8000" times larger than the moon; tho his measurements, taken by themselves, give no clue to the actual bulk of either body.

These conclusions, be it understood, are absolutely valid inferences—nay, demonstrations—from the measurements involved, provided only that *these measurements* have been correct. Unfortunately, the angle of the triangle we have just seen measured is exceedingly difficult to determine with accuracy, while at the same time, as a moment's reflection will show, it is so large an angle that a very slight deviation from the truth will greatly affect the distance at which its line joins the other side of the triangle. Then again, it is virtually impossible to tell the precise moment when the moon is at half, as the line it gives is not so sharp that we can fix it with absolute accuracy. There is, moreover, another element of error due to the *refraction of light.*

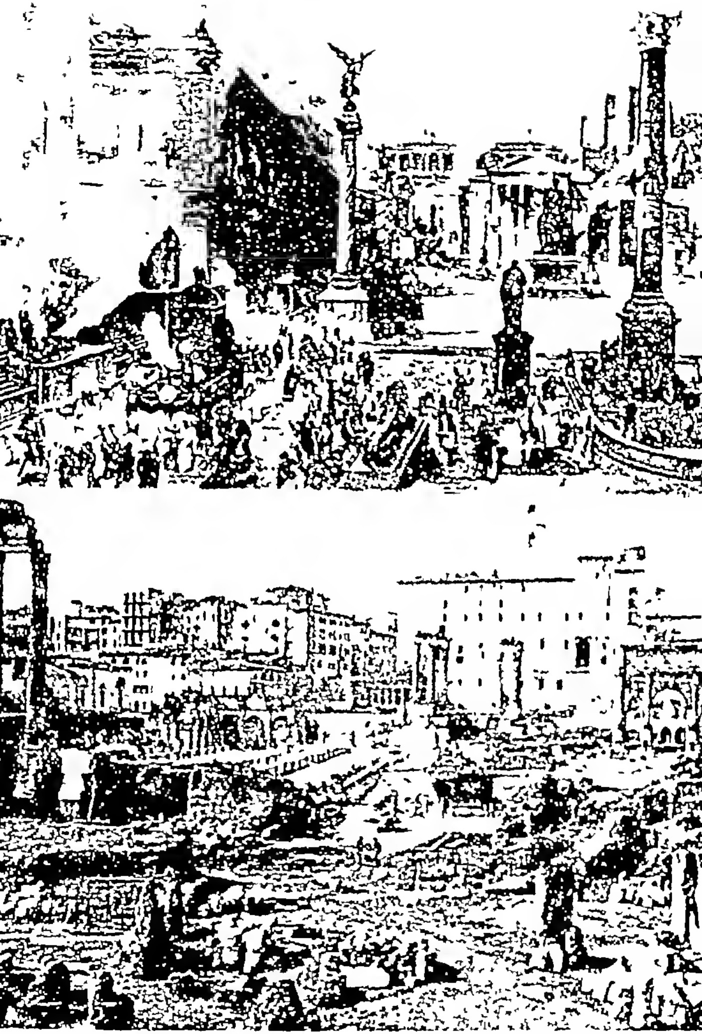
Aristarchus estimated the angle at eighty-seven degrees. Had his instrument been more precise, and had he been able to take account of all the elements of error, he would have found it eighty-seven degrees and fifty-two minutes. The difference of measurement seems slight; but it sufficed to make the computations differ absurdly from the truth. The sun is really not merely eighteen times but more than two hundred times the distance of the moon, as Wendelein discovered on repeating the experiment of Aristarchus about two thousand years later.

Yet this discrepancy does not in the least take away from the validity of the method which Aristarchus employed. Moreover, his conclusion, stated in general terms, was perfectly correct; the sun is many times more distant than the moon and vastly larger than that body Granted, then, that the moon is, as Aristarchus correctly believed, considerably less in size than the earth, the sun must be enormously larger than the earth; and this is the vital inference which, more than any other, must have seemed to Aristarchus to confirm the suspicion that the sun and not the earth is the center of the planetary system.

It seemed to him inherently improbable that an enormously large body like the sun should revolve about a small one such as the earth. And again, it seemed inconceivable that a body so distant as the sun should whirl through space so rapidly as to make the circuit of its orbit in twenty-four hours. But, on the other hand, that a small body like the earth should revolve about the gigantic sun seemed inherently probable. This proposition granted, the rotation of the earth on its axis follows as a necessary consequence in explanation of the seeming motion of the stars. Here, then, was the heliocentric doctrine reduced to a virtual demonstration by Aristarchus of Samos, somewhere about the middle of the third century B.C.

All the conclusions of Aristarchus are stated in relative terms. He nowhere attempts to estimate the precise size of the earth, of the moon, or of the sun, or the actual distance of one of these bodies from another. The obvious reason for this is that no data were at hand from which to make such precise measurements. Had Aristarchus known the size of any one of the bodies in question, he might readily, of course, have determined the size of the others by the mere application of his relative scale.

Where Aristarchus halted, however, another worker of the same period took the task in hand and by an altogether wonderful measurement determined the size of the earth, and thus brought the scientific theories of cosmology to their climax. This supplementor of the work of Aristarchus was Eratosthenes of Alexandria.



THE ROMAN FORUM RESTORED AND IN RUINS

IV

ERATOSTHENES, "THE SURVEYOR OF THE WORLD"

AN altogether remarkable man was this native of Cyrene, who came to Alexandria from Athens to be the chief librarian of Ptolemy Euergetes. He was not merely an astronomer and a geographer, but a poet and grammarian as well. His contemporaries jestingly called him Beta the Second, because he was said through the universality of his attainments to be "a second Plato" in philosophy, "a second Thales" in astronomy, and so on throughout the list. He was also called the "surveyor of the world," in recognition of his services to geography. Hipparchus said of him, perhaps half jestingly, that he had studied astronomy as a geographer and geography as an astronomer. It is not quite clear whether the epigram was meant as compliment or as criticism. Similar phrases have been turned against men of versatile talent in every age.

Be that as it may, Eratosthenes passed into history as the father of scientific geography and of scientific chronology; as the astronomer who first measured the obliquity of the ecliptic; and as the inventive genius who performed the astounding feat of measuring the size of the globe on which we live at a time when only a relatively small portion of that globe's surface was known to civilized man. It is no discredit to approach astronomy as a geographer and geography as an astronomer if the results are such as these.

What Eratosthenes really did was to approach both astronomy and geography from two seemingly divergent points of attack—namely, from the standpoint of the geometer and also from that of the poet. Perhaps no man in any age has brought a better combination of observing and imaginative faculties to the aid of science.

Nearly all the discoveries of Eratosthenes are associated with observations of the shadows cast by the sun. In the study of the heavenly bodies, much depends on the measurement of angles. Now the easiest way in which angles can be measured, when solar angles are in question, is to pay attention, not to the sun itself, but to the shadow that it casts.

The gnomon is the most primitive, and long remained the most important, of astronomical instruments. It is believed that Eratosthenes invented an important modification of the gnomon which was elaborated afterwards by Hipparchus and called an armillary sphere. This consists essentially of a small gnomon, or perpendicular post, attached to a plane representing the earth's equator and a hemisphere in imitation of the earth's surface. With the aid of this, the shadow cast by the sun could be very accurately measured. It involves no new principle. Every perpendicular post or object of any kind placed in the sunlight casts a shadow from which the angles now in question could be roughly measured. The province of the armillary sphere was to make these measurements extremely accurate.

With the aid of this implement, Eratosthenes carefully noted the longest and the shortest shadows cast by the gnomon—that is to say, the shadows cast on the days of the solstices. He found that the distance between the tropics thus measured represented 47° 42′ 39″ of arc. One-half of this, or 23° 51′ 19.5″, represented the obliquity of the ecliptic—that is to say, the angle by which the earth's axis dipped from the perpendicular with reference to its orbit.

This was a most important observation, and because of its accuracy it has served modern astronomers well for comparison in measuring the trifling change due to our earth's slow, swinging wobble. For the earth, be it understood, like a great top spinning through space, holds its position with relative but not quite absolute fixity.

It must not be supposed, however, that the experiment in question was quite new with Eratosthenes. His merit consists rather in the accuracy with which he made his observation than in the novelty of the conception; for it is recorded that Eudoxus, a full century earlier, had remarked the obliquity of the ecliptic. That observer had said that the obliquity corresponded to the side of a pentadecagon, or fifteen-sided figure, which is equivalent in modern phraseology to twenty-four degrees of arc. But so little is known regarding the way in which Eudoxus reached his estimate that the measurement of Eratosthenes is usually spoken of as if it were the first effort of the kind.

Much more striking, at least in its appeal to the popular imagination, was that other great feat which Eratosthenes performed with the aid of his perfected gnomon—the measurement of the earth itself. When we reflect that at this period the portion of the earth open to observation extended only from the Straits of Gibraltar on the west to India on the east, and from the North Sea to Upper Egypt, it certainly seems enigmatical—at first thought almost miraculous—that an observer should have been able to measure the entire globe. That he should have accomplished this through observation of nothing more than a tiny bit of Egyptian territory and a glimpse of the sun's shadow makes it seem but the more wonderful. Yet the method of Eratosthenes, like many another enigma, seems simple enough once it is explained. It required but the application of a very elementary knowledge of the geometry of circles, combined with the use of a fact or two from local geography — which detracts nothing from the genius of the man who could reason from such simple premises to so wonderful a conclusion.

Stated in a few words, the experiment of Eratosthenes was this. His geographical studies had taught him that the town of Syene lay directly south of Alexandria, or, as we should say, on the same meridian of longitude. He had learned, further, that Syene lay directly under the tropic, since it was reported that at noon on the day of the summer solstice the gnomon there cast no shadow, while a deep well was illumined to the bottom by the sun. A third item of knowledge, supplied by the surveyors of Ptolemy, made the distance between Syene and Alexandria five thousand stadia. These, then, were the preliminary data required by Eratosthenes. Their significance consists in the fact that here is a measured bit of the earth's arc five thousand stadia in length. If we could find out what angle that bit of arc subtends, a mere matter of multiplication would give us the size of the earth. But how determine this all-important number?

The answer came through reflection on the relations of concentric circles. If you draw any number of circles, of whatever size, about a given center, a pair of radii drawn from that center will cut arcs of the same relative *size* from all the circles. One circle may be so small that the actual arc subtended by the radii in a given case may be but an inch in length, while another circle is so large that its corresponding arc is measured in millions of miles; but in each case the same number of so-called degrees will represent the relation of each arc to its circumference.

Now, Eratosthenes knew, as just stated, that the sun, when on the meridian on the day of the summer solstice, was directly over the town of Syene. This meant that at that moment a radius of the earth projected from Syene would point directly toward the sun. Meanwhile, of course, the zenith would represent the projection of the radius of the earth passing through Alexandria. All that was required, then, was to measure, at Alexandria, the angular distance of the sun from the zenith at noon on the day of the solstice to secure an approximate measurement of the arc of the sun's circumference, corresponding to the arc of the earth's surface represented by the measured distance between Alexandria and Syene.

The reader will observe that the measurement could not be absolutely accurate, because it is made from the surface of the earth, and not from the earth's center, but the size of the earth is so insignificant in comparison with the distance of the sun that this slight discrepancy could be disregarded.

The way in which Eratosthenes measured this angle was very simple. He merely measured the angle of the shadow which his perpendicular gnomon at Alexandria cast at midday on the day of the solstice, when, as already noted, the sun was directly perpendicular at Syene. Now a glance at the diagram will make it clear that the measurement of this angle of the shadow is merely a convenient means of determining the precisely equal opposite angle subtending an arc of an imaginary circle passing through the sun; the arc which, as already explained, corresponds with the arc of the earth's surface represented by the distance between Alexandria and Syene. He found this angle to represent 7° 12′, or one-fiftieth of the circle. Five thousand stadia, then, represent one-fiftieth of the earth's circumference; the entire circumference being, therefore, 250,000 stadia.

Unfortunatly, we do not know which one of the various measurements used in antiquity is represented by the stadia of Eratosthenes. According to the researches of Lepsius, however, the stadium in question represented 180 meters, and this would make the earth, according to the measurement of Eratosthenes, about twenty-eight thousand miles in circumference, an answer sufficiently exact to justify the wonder which the experiment excited in antiquity, and the admiration with which it has ever since been regarded.

Of course it is the method, and not its details or its exact results, that excites our interest. And beyond question the method was an admirable one. Its result, however, could not have been absolutely accurate, because, while correct in principle, its data were defective. In point of fact Syene did not lie precisely on the same meridian as Alexandria, neither did it lie exactly on the tropic. Here, then, are two elements of inaccuracy. Moreover, it is doubtful whether Eratosthenes made allowance, as he should have done, for the semi-diameter of the sun in measuring the angle of the shadow. But these are mere details, scarcely worthy of mention from our present standpoint. What perhaps is deserving of more attention is the fact that this epoch-making measurement of Eratosthenes may not have been the first one to be made.

A passage of Aristotle records that the size of the earth was said to be 400,000 stadia. Some commentators have thought that Aristotle merely referred to the area of the inhabited portion of the earth and not to the circumference of the earth itself, but his words seem doubtfully susceptible of this interpretation; and if he meant, as his words seem to imply, that philosophers of his day had a tolerably precise idea of the globe, we must assume that this idea was based upon some sort of measurement. The recorded size, 400,000 stadia, is a sufficient approximation to the truth to suggest something more than a mere unsupported guess. Now, since Aristotle died more than fifty years before Eratosthenes was born, his report as to the alleged size of the earth certainly has a suggestiveness that cannot be overlooked; but it arouses speculations without giving an inkling as to their solution.

If Eratosthenes had a precursor as an earth-measurer, no hint or rumor has come down to us that would enable us to guess who that precursor may have been. His personality is as deeply enveloped in the mists of the past as are the personalities of the great prehistoric discoverers. For the purpose of the historian, Eratosthenes must stand as the inventor of the method with which his name is associated, and as the first man of whom we can say with certainty that he measured the size of the earth. Right worthily, then, had the Alexandrian philosopher won his proud title of "surveyor of the world."

RUINS OF BAKERY AT POMPEII

V

CTESIBIUS AND HERO: MAGICIANS OF ALEXANDRIA

A GENERATION or two later there was a man in Alexandria who was exercising a strangely inventive genius over mechanical problems of another sort; a man who, following the example set by Archimedes a century before, was studying the problems of matter and putting his studies to practical application through the invention of weird devices.

The man's name was Ctesibius. We know scarcely more of him than that he lived in Alexandria, probably in the first half of the second century B.C. His antecedents, the place and exact time of his birth and death, are quite unknown. Neither are we quite certain as to the precise range of his studies or the exact number of his discoveries.

It appears that he had a pupil named Hero, whose personality, unfortunately, is scarcely less obscure than that of his master, but who wrote a book through which the record of the master's inventions was preserved to posterity. Hero, indeed, wrote several books, tho only one of them has been preserved. The ones that are lost bear the following suggestive titles: *On the Construction of Slings; On the Construction of Missiles; On the Automaton; On the Method of Lifting Heavy Bodies, On the Dioptric or Spying-tube.* The work that remains is called *Pneumatics,* and so interesting a work it is as to make us doubly regret the loss of its companion volumes. Had these other books been preserved we should doubtless have a clearer insight than is now possible into some at least of the mechanical problems that exercised the minds of the ancient philosophers.

The book that remains is chiefly concerned, as its name implies, with the study of gases, or, rather, with the study of a single gas, this being, of course, the air. But it tells us also of certain studies in the dynamics of water that are most interesting, and for the historian of science most important.

Unfortunately, the pupil of Ctesibius, whatever his ingenuity, was a man with a deficient sense of the ethics of science. He tells us in his preface that the object of his book is to record some ingenious discoveries of others, together with additional discoveries of his own, but nowhere in the book itself does he give us the slightest clue as to where the line is drawn between the old and the new.

Once, in discussing the weight of water, he mentions the law of Archimedes regarding a floating body, but this is the only case in which a scientific principle is traced to its source or in which credit is given to any one for a discovery. This is the more to be regretted because Hero has discussed at some length the theories involved in the treatment of his subject. This reticence on the part of Hero, combined with the fact that such somewhat later writers as Pliny and Vitruvius do not mention Hero's name, while they frequently mention the name of his master, Ctesibius, has led modern critics to a somewhat skeptical attitude regarding the position of Hero as an actual discoverer.

The man who would coolly appropriate some discoveries of others under cloak of a mere prefatorial reference was perhaps an expounder rather than an innovator, and had, it is shrewdly suspected, not much of his own to offer. Meanwhile, it is tolerably certain that Ctesibius was the discoverer of the principle of the siphon, of the forcing-pump, and of a pneumatic organ. An examination of Hero's book will show that these are really the chief principles involved in most of the various interesting mechanisms which he describes. We are constrained, then, to believe that the inventive genius who was really responsible for the mechanisms we are about to describe was Ctesibius, the master. Yet we owe a debt of gratitude to Hero, the pupil, for having given wider vogue to these discoveries, and in particular for the discussion of the principles of hydrostatics and pneumatics contained in the introduction to his book. This discussion furnishes us almost our only knowledge as to the progress of Greek philosophers in the field of mechanics since the time of Archimedes.

The main purpose of Hero in his preliminary thesis has to do with the nature of matter, and recalls, therefore, the studies of Anaxagoras and Democritus. Hero, however, approaches his subject from a purely material or practical standpoint. He is an explicit champion of what we nowadays call the molecular theory of matter.

"Every body," he tells us," is composed of minute particles, between which are empty spaces less than these particles of the body. It is, therefore, erroneous to say that there is no vacuum except by the application of force, and that every space is full either of air or water or some other substance. But in proportion as any one of these particles recedes, some other follows it and fills the vacant space; therefore there is no continuous

Hero brings forward some thoroughly convincing proofs of the thesis he is maintaining. "If there were no void places between the particles of water," he says, "the rays of light could not penetrate the water; moreover, another liquid, such as wine, could not spread itself through the water, as it is observed to do, were the particles of water absolutely continuous."

The latter illustration is one the validity of which appeals as forcibly to the physicists of today as it did to Hero. The same is true of the argument drawn from the compressibility of gases. Hero has evidently made a careful study of this subject. He knows that an inverted tube full of air may be immersed in water without becoming wet on the inside, proving that air is a physical substance; but he knows also that this same air may be caused to expand to a much greater bulk by the application of heat, or may, on the other hand, be condensed by pressure, in which case, as he is well aware, the air exerts force in the attempt to regain its normal bulk. But, he argues, surely we are not to believe that the particles of air expand to fill all the space when the bulk of air as a whole expands under the influence of heat; nor can we conceive that the particles of normal air are in actual contact, else we should not be able to compress the air. Hence his conclusion, which, as we have seen, he makes general in its application to all matter, that there are spaces, or, as he calls them, vacua, between the particles that go to make up all substances, whether liquid, solid, or gaseous.

Here, clearly enough, was the idea of the "atomic" nature of matter accepted as a fundamental notion. The argumentative attitude assumed by Hero shows that the doctrine could not be expected to go unchallenged. But, on the other hand, there is nothing in his phrasing to suggest an intention to claim originality for any phase of the doctrine. We may infer that in the three hundred years that had elapsed since the time of Anaxagoras, that philosopher's idea of the molecular nature of matter had gained fairly wide currency.

As to the expansive power of gas, which Hero describes at some length without giving us a clue to his authorities, we may assume that Ctesibius was an original worker, yet the general facts involved were doubtless much older than his day. Hero, for example, tells us of the cupping-glass used by physicians, which he says is made into a vacuum by burning up the air in it; but this apparatus had probably been long in use, and Hero mentions it not in order to describe the ordinary cupping-glass which is referred to, but a modification of it. He refers to the old form as if it were something familiar to all.

Again, we know that Empedocles studied the pressure of the air in the fifth century B.C., and discovered that it would support a column of water in a closed tube, so this phase of the subject is not new. But there is no hint anywhere before this work of Hero of a clear understanding that the expansive properties of the air when compressed, or when heated, may be made available as a motor power. Hero, however, has the clearest notions on the subject and puts them to the practical test of experiment.

Thus he constructs numerous mechanisms in which the expansive power of air under pressure is made to do work, and others in which the same end is accomplished through the expansive power of heated air.

For example, the doors of a temple are made to swing must have filled the minds of the pious observers with bewilderment and wonder, serving a most useful purpose for the priests, who alone, we may assume, were in the secret.

There were two methods by which this apparatus was worked. In one the heated air pressed on the water in a close retort connected with the altar, forcing water out of the retort into a bucket, which by its weight applied a force through pulleys and ropes that turned the standards on which the temple doors revolved. When the fire died down the air contracted, the water was siphoned back from the bucket, which, being thus lightened, let the doors close again through the action of an ordinary weight. The other method was a slight modification, in which the retort of water was dispensed with and a leather sack like a large football substituted. The ropes and pulleys were connected with this sack, which exerted a pull when the hot air expanded, and which collapsed and thus relaxed its strain when the air cooled. A glance at the illustrations taken from Hero's book will make the details clear.

Other mechanisms utilized a somewhat different combination of weights, pulleys, and siphons, operated by the expansive power of air, unheated but under pressure, such pressure being applied with a force-pump, or by the weight of water running into a closed receptacle. One such mechanism gives us a constant jet of water or perpetual fountain. Another curious application of the principle furnishes us with an elaborate toy, consisting of a group of birds which alternately whistle or are silent, while an owl seated on a neighboring perch turns toward the birds when their song begins and away from them when it ends.

The "singing" of the birds, it must be explained, is produced by the expulsion of air through tiny tubes passing up through their throats from a tank below. The owl is made to turn by a mechanism similar to that which manipulates the temple doors. The pressure is supplied merely by a stream of running water, and the periodical silence of the birds is due to the fact that this pressure is relieved through the automatic siphoning off of the water when it reaches a certain height. The action of the siphon, it may be added, is correctly explained by Hero as due to the greater weight of the water in the longer arm of the bent tube.

As before mentioned, the siphon is repeatedly used in these mechanisms of Hero. The diagram will make clear the exact application of it in the present most ingenious mechanism. We may add that the principle of the whistle was a favorite one of Hero. By the aid of a similar mechanism he brought about the blowing of trumpets when the temple doors were opened, a phenomenon which must greatly have enhanced the mystification. It is possible that this principle was utilized also in connection with statues to produce seemingly supernatural effects. This may be the explanation of the tradition of the speaking statue in the temple of Ammon at Thebes.

The utilization of the properties of compressed air was not confined, however, exclusively to mere toys, or to produce miraculous effects. The same principle was applied to a practical fire-engine, worked by levers and force-pumps; an apparatus, in short, altogether similar to that still in use in rural districts. A slightly different application of the motive power of expanding air is furnished in a very curious toy called "the dancing of revolving arms precisely like those of the ordinary revolving fountain with which we are accustomed to water our lawns, the revolving arms being attached to a plane on which several pairs of statuettes representing dancers are placed.

An even more interesting application of this principle of setting a wheel in motion is furnished in a mechanism which must be considered the earliest of steam-engines. Here, as the name implies, the gas supplying the motive power is actually steam. The apparatus made to revolve is a globe connected with the steam-retort by a tube which serves as one of its axes, the steam escaping from the globe through two bent tubes placed at either end of an equatorial diameter.

It does not appear that Hero had any thought of making practical use of this steam-engine. It was merely a curious toy—nothing more. Yet had not the age that succeeded that of Hero been one in which inventive genius was dormant, some one must soon have hit upon the idea that this steam-engine might be improved and made to serve a useful purpose. As the case stands, however, there was no advance made upon the steam motor of Hero for almost two thousand years. And, indeed, when the practical application of steam was made, toward the close of the eighteenth century, it was made probably quite without reference to the experiment of Hero, tho knowledge of his toy may perhaps have given a clue to Watt or his predecessors.

In recent times there has been a tendency to give to this steam-engine of Hero something more than full meed of appreciation. To be sure, it marked a most important principle in the conception that steam might be used as a motive power, but otherwise it was much too primitive to be of any importance.

But there is one mechanism described by Hero which was a most explicit anticipation of a device, which presumably soon went out of use, and which was not reinvented until toward the close of the nineteenth century. This was a device which has become familiar in recent times as the penny-in-the-slot machine. When toward the close of the nineteenth century some inventive craftsman hit upon the idea of an automatic machine to supply candy, a box of cigarets, or a whiff of perfumery, he may or may not have borrowed his idea from the slot-machine of Hero; but in any event, instead of being an innovator he was really two thousand years behind the times, for the slot-machine of Hero is the precise prototype of these modern ones.

The particular function which the mechanism of Hero was destined to fulfil was the distribution of a jet of water, presumably used for sacramental purposes, which was given out automatically when a five-drachma coin was dropped into the slot at the top of the machine. The internal mechanism of the machine was simple enough, consisting merely of a lever operating a valve which was opened by the weight of the coin dropping on the little shelf at the end of the lever, and which closed again when the coin slid off the shelf. The description suggests how simple this mechanism was. Yet to the worshipers, who probably had entered the temple through doors miraculously opened, and who now witnessed this seemingly intelligent response of a machine, the result must have seemed mystifying enough; and, indeed, for us also, when we consider how relatively crude was the mechanical knowledge of the time, this must seem nothing less than marvelous.

spurt of holy water, can we realize that this is the land of the Pharaohs, not England or America; that the kingdom of the Ptolemies is still at its height; that the republic of Rome is mistress of the world; that all Europe north of the Alps is inhabited solely by barbarians; that Cleopatra and Julius Cæsar are yet unborn; that the Christian era has not yet begun? Truly, it seems as if there could be no new thing under the sun.

LVCRETI SATRI

A BILLBOARD AT POMPEII

Clitimestra . Nutrix .

Clitim Quid segnis anime tuta consilia expetis Lege

Quid fluctuaris clausa melior uia est

Licuit pudicos coniugis quondam thoros

Et sceptra casta uidua tutari fide

Periere mores . ius . decus . pietas . fides

Et qui redire nescit cum perit pudor

Da frena et omnem prona nequitiam incita

Per scelera . semper sceleribus tutum est iter

Tecum ipsa nunc euolue feminee dolos

Quod ulla coniux perfida atque impos sui

Amore ceco quod nouercales manus

Ause . quod ardens impia uirgo face

Phasyacis, cupiens, regna thesalica trabe

Ferrum uenena uel micenean domum

Coniuncta socio profuge furtiua rate

Quid timida loqueris furta exilium et fugas

Soror ista fecit te decet maius nefas

Regina danaum et inclitum lede genus .

Nutri Quid tacita uersas quid ue consilii impotens

Tumido feroces impetus animo geris

Licet ipsa sileas totus in uultu est dolor

l' proinde Preme quicquid est spatium ac tempus tibi

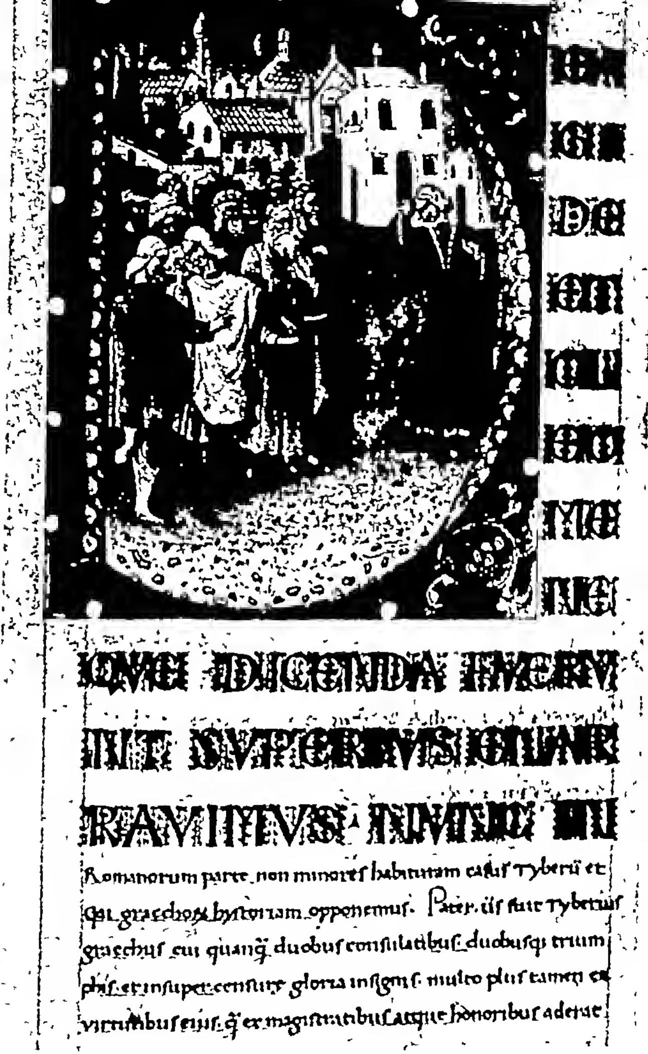
Quod ratio nequit sepe sanauit mora

Clite Maiora cruciant quam ut moras possim pati

Flamme medullas et cor exurunt meum

Mixtus dolori subdidit stimulos timor

Inuidia pulsat pectus hinc animum iugo



QVE DICENDA FVERV
NT SVPERIVS ENAR
RAVIMVS NVNC IN

Romanorum parte. non minoreſ habituram caſuſ Tyberii et
Gai. gracchorum hyſtoriam opponemuſ. Pater. illiſ fuit Tyberiuſ
gracchuſ. cui quanquam duobuſ conſulatibuſ. duobuſque trium
phiſ. et inſuper cenſure gloria inſigniſ. multo pluſ tamen ex
virtutibuſ eiuſ. quam ex magiſtratibuſ atque honoribuſ adeptuſ

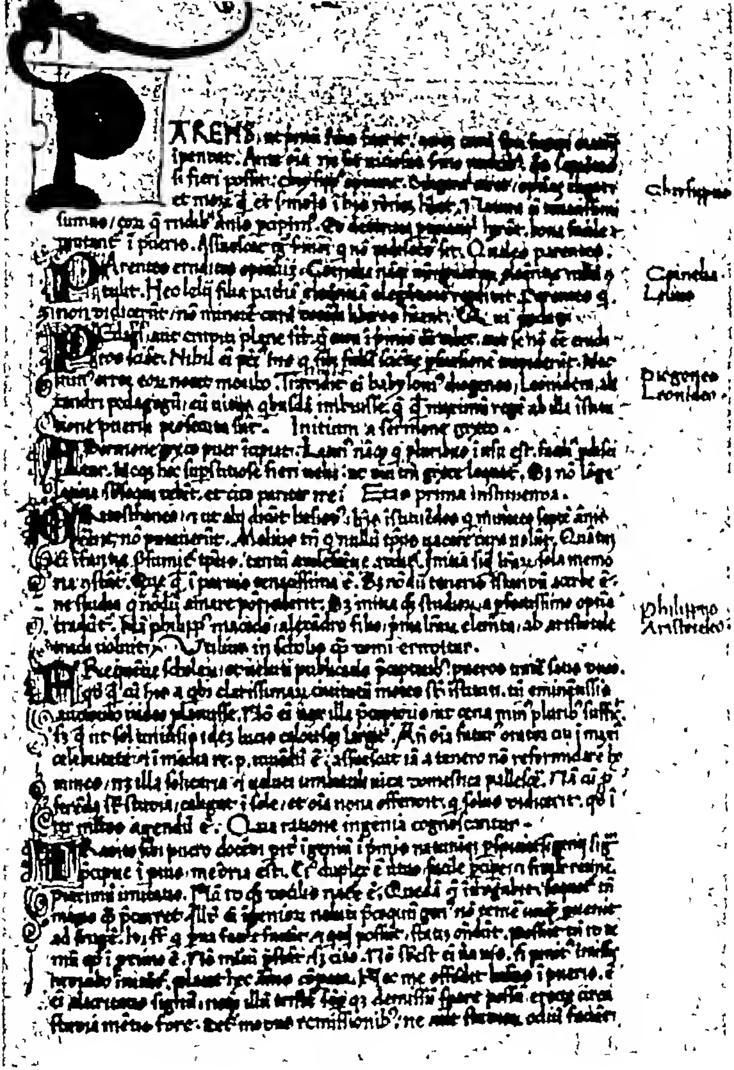
PLUTARCH (ABOUT A D 1450)

EXPLICIT FELICIT.

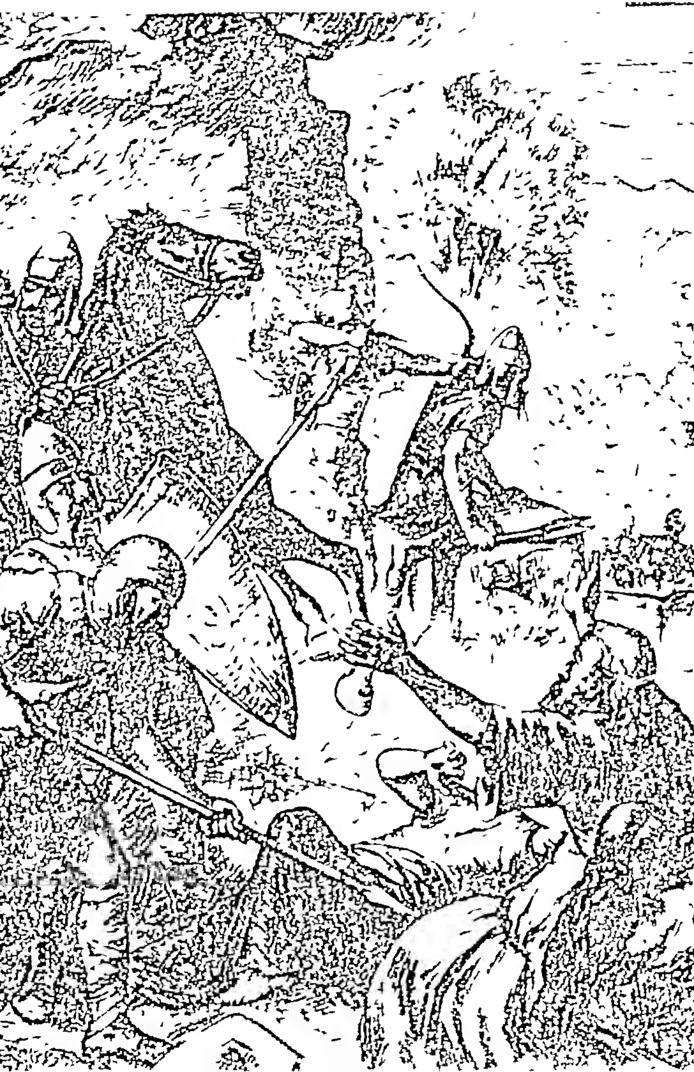
INCIPIT EIVSDEM LIBER QVINTVS AD QVINTVM METELLVM. LEGE FELICITER.

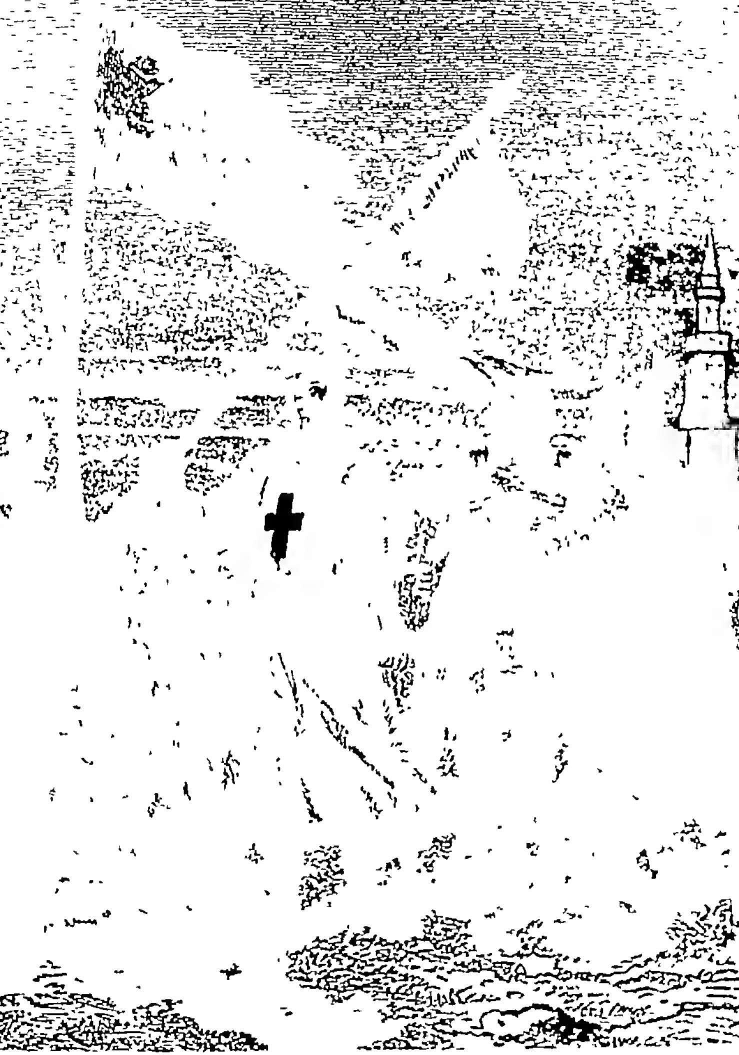
QVINTVS METELLVS. Q. F. CELER proconsul sal. d. M. Tullio Ciceroni. Si uales bene est. Existimaram. Existimaram pro mutuo inter nos animo et pro reconciliata gratia nec absentem ludibrio lesum iri: nec Metellum fratrem ob dictum capite ac fortunis per te oppugnatum iri. Quem si parum pudor ipsius defendebat: debebat uel familiae nostrae dignitas uel meum studium erga uos remque p. satis subleuare. Nunc uideo illum circumuentum me desertum a quibus minime conueniebat. Itaque in luctu et squalore sum: qui prouinciae. qui exercitui presum: qui bellum gero. Quae quoniam nec ratione nec maiorum nostrorum clementia administrastis: non erit mirandum si uos penitebit. Te tam mobili in me meosque esse animo non sperabam. Me interea nec domesticus dolor nec cuiusque iniuria ab re p. abducet.

MARCVS TVLLIVS. M. FI. CICERO. Q. metello. Q. fi. celeri proconsul sal. p. d.. Si tu exercitusque ualetis bene est. Scribis ad me te existimasse pro mutuo inter nos animo et pro reconciliata gratia numquam te a me ludibrio lesum iri: Quod cuiusmodi sit satis intelligere non possum. Sed tamen suspicor ad te esse allatum me in senatum quom disputarem permultos esse: qui rem p. a me conseruatam dolerent: dixisse a te propinquos tuos quibus negare non potuisses impetrasse: ut ea quae statuisses tibi in sena

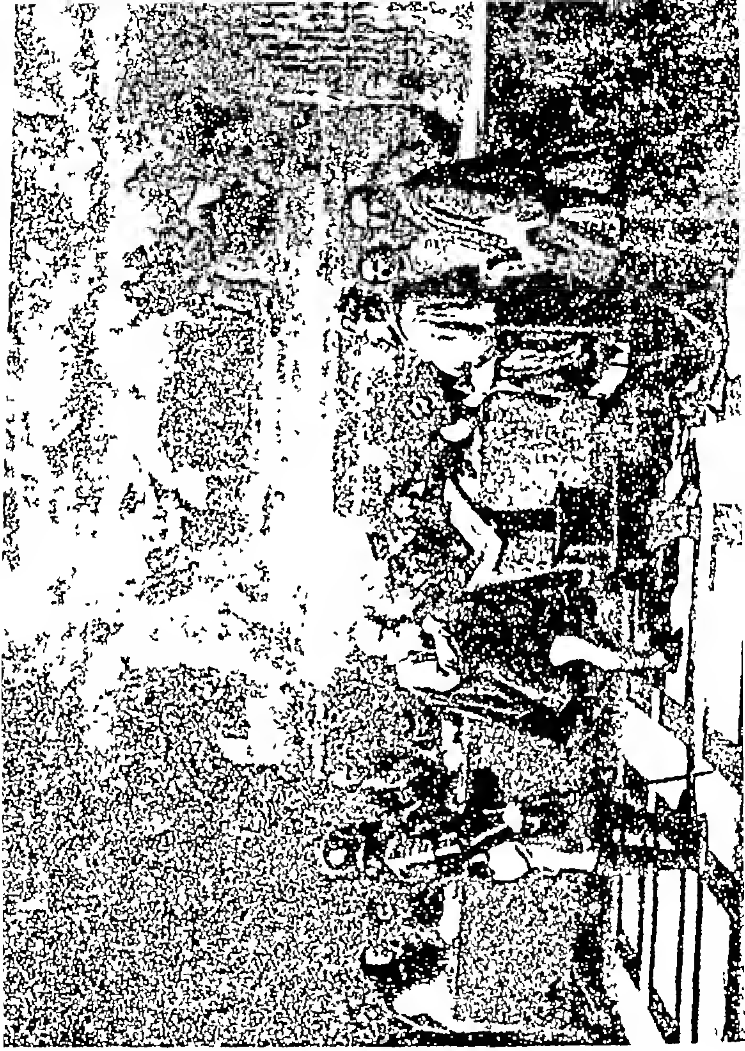


QUINTILIAN (A.D. 1467)





CRUSADERS



OBSTINATE GALILEO ("AND YET IT DOES MOVE")

VI

GALILEO AND THE NEW PHYSICS

AFTER Galileo had felt the strong hand of the Inquisition, in 1632, he was careful to confine his researches, or at least his publications, to topics that seemed free from theological implications. In doing so he reverted to the field of his earliest studies—namely, the field of mechanics; and the *Dialoghi delle Nuove Scienze*, which he finished in 1636, and which was printed two years later, attained a celebrity no less than that of the heretical dialog that had preceded it. The later work was free from all apparent heresies, yet perhaps it did more toward the establishment of the Copernican doctrine, through the teaching of correct mechanical principles, than the other work had accomplished by a more direct method.

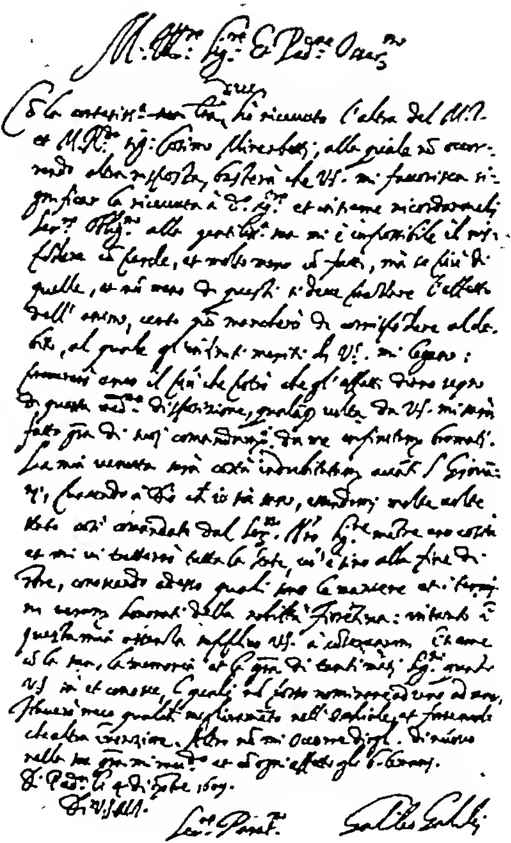
Galileo's astronomical discoveries were, as we have seen, in a sense accidental; at least, they received their inception through the inventive genius of another. His mechanical discoveries, on the other hand, were the natural output of his own creative genius. At the very beginning of his career, while yet a very young man, tho a professor of mathematics at Pisa, he had begun that onslaught upon the old Aristotelian ideas which he was to continue throughout his life. At the famous lean-

in the

falsity of the Aristotelian doctrine that the velocity of falling bodies is proportionate to their weight. There is perhaps no fact more strongly illustrative of the temper of the Middle Ages than the fact that this doctrine, as taught by the Aristotelian philosopher, should so long have gone unchallenged. Now, however, it was put to the test; Galileo released a half-pound weight and a hundred-pound cannon-ball *from near the top of the* tower, and, needless to say, they reached the ground together.

Of course, the spectators were but little pleased with what they saw. They could not doubt the evidence of their own senses as to the particular experiment in question; they could suggest, however, that the experiment involved a violation of the laws of nature through the practise of magic. To controvert so firmly established an idea savored of heresy. The young man guilty of such iconoclasm was naturally looked at askance by the scholarship of his time. Instead of being applauded, he was hissed, and he found it expedient presently to retire from Pisa.

Fortunately, however, the new spirit of progress had made itself felt more effectively in some other portions of Italy, and so Galileo found a refuge and a following in Padua, and afterwards in Florence; and while, as we have seen, he was obliged to curb his enthusiasm regarding the subject that was perhaps nearest his heart—the promulgation of the Copernican theory — yet he was permitted in the main to carry on his experimental observations unrestrained. These experiments gave him a place of unquestioned authority among his contemporaries, and they have transmitted his name to posterity as that of one of the greatest of experimenters and the virtual founder of modern mechanical science.



M.to Ill.re Sig.re et Pad.ne Oss.mo

Con la cortesiss.a sua lett.a ho ricevuto l'altra del M.to Ill.re
et M.to R.do Sig. Cosimo [illegible]; alla quale non occor-
rendo altra risposta, basterà che V.S. mi favorisca ri-
graziar la ricevuta a d.o Sig.re et insieme ricordarmeli
Ser.re Oblig.mo alle gentilezze ma mi è impossibile il ri-
storare con parole, et molto meno co' fatti, ma se [illegible] di
quelle, et [illegible] meno di questi si deve [illegible] l'affetto
dell'animo, certo io non mancherò di manifestare alla
[illegible], al quale gl'infiniti meriti di V.S. mi legano;
[illegible] ancora il [illegible] che [illegible] che gl'affetti dieno segno
di questa mia [illegible] dispositione, qualunque volta da V.S. mi [illegible]
fatto gra.a di suoi comandam.ti da me infinitam.te bramati.
La mia venuta sarà costà indubitatam.te avanti S. Giovan-
ni, [illegible] a Dio et io più non, [illegible] nelle altre
[illegible] costì [illegible] dal Ser.mo Mio Sig.re mentre ero costà
et mi vi tratterrò tutta la state, cioè fino alla fine di
[illegible], conoscendo adesso quali sono le maniere et i termini
[illegible] honorevoli della nobiltà Fiorentina: intanto in
questa mia assenza supplico V.S. a conservarmi l'amore
et la sua, la memoria et la gra.a di tanti miei Sig.ri quanti
V.S. sa et conosce, li quali nel [illegible] raccomandarà uno ad uno,
[illegible] mia qualità [illegible] nell'[illegible], et favorendo
che altra occasione. Altro non mi occorre dirgli. Di nuovo
[illegible] mi raccom.do et ad ogni affetto gli b. le mani.
Di Pad.a li 4 di [illegible] 1609.

Di V.S. M.to Ill.re

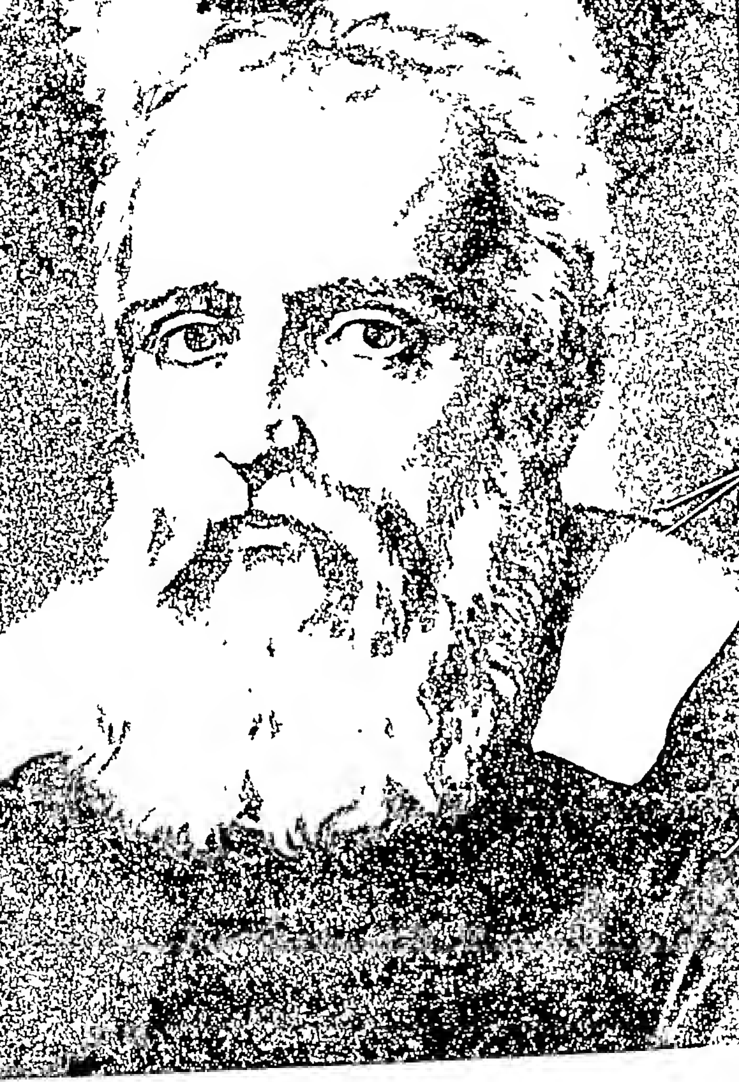
Ser.re [illegible]

Galileo Galilei

GALILEO GALILEI

Date 1609

Brit. Museum, Add MS 23,139



GALILEO

The experiments in question range over a wide field; but for the most part they have to do with moving bodies and with questions of force, or, as we should now say, of energy. The experiment at the leaning tower showed that the velocity of falling bodies is independent of the weight of the bodies, provided the weight is sufficient to overcome the resistance of the atmosphere. Later experiments with falling bodies led to the discovery of laws regarding the accelerated velocity of fall. Such velocities were found to bear a simple relation to the period of time from the beginning of the fall. Other experiments, in which balls were allowed to roll down inclined planes, corroborated the observation that the pull of gravitation gave a velocity proportionate to the length of fall, whether such fall were direct or in a slanting direction.

These studies were associated with observations on projectiles, regarding which Galileo was the first to entertain correct notions. According to the current idea, a projectile fired, for example, from a cannon, moved in a straight horizontal line until the propulsive force was exhausted, and then fell to the ground in a perpendicular line. Galileo taught that the projectile begins to fall at once on leaving the mouth of the cannon and traverses a parabolic course. According to his idea, which is now familiar to every one, a cannon-ball dropped from the level of the cannon's muzzle will strike the ground simultaneously with a ball fired horizontally from the cannon.

As to the paraboloid course pursued by the projectile, the resistance of the air is a factor which Galileo could not accurately compute, and which interferes with the ractical realization of his theory. But this is a minor tation acts in precisely the same way upon all unsupported bodies, whether or not such bodies be at the same time acted upon by a force of translation.

Out of these studies of moving bodies was gradually developed a correct notion of several important general laws of mechanics—laws a knowledge of which was absolutely essential to the progress of physical science. The belief in the rotation of the earth made necessary a clear conception that all bodies at the surface of the earth partake of that motion quite independently of their various observed motions in relation to one another. This idea was hard to grasp, as an oft-repeated argument shows. It was asserted again and again that, if the earth rotates, a stone dropped from the top of a tower could not fall at the foot of the tower, since the earth's motion would sweep the tower far away from its original position while the stone is in transit.

This was one of the stock arguments against the *earth's motion, yet it was one that could be refuted* with the greatest ease by reasoning from strictly analogous experiments. It might readily be observed, for example, that a stone dropped from a moving cart does not strike the ground directly below the point from which it is dropped, but partakes of the forward motion of the cart.

If any one doubt this he has but to jump from a moving cart to be given a practical demonstration of the fact that his entire body was in some way influenced by the motion of translation. Similarly, the simple experiment of tossing a ball from the deck of a moving ship will convince any one that the ball partakes of the motion of the ship, so that it can be manipulated precisely as if the manipulator were standing on the earth. In short, every-day experience gives us illustrations of what might be called compound motion, which makes it seem altogether plausible that, if the earth is in motion, objects at its surface will partake of that motion in a way that does not interfere with any other movements to which they may be subjected.

As the Copernican doctrine made its way, this idea of compound motion naturally received more and more attention, and such experiments as those of Galileo prepared the way for a new interpretation of the mechanical principles involved.

The great difficulty was that the subject of moving bodies had all along been contemplated from a wrong point of view. Since force must be applied to an object to put it in motion, it was perhaps not unnaturally assumed that similar force must continue to be applied to keep the object in motion. When, for example, a stone is thrown from the hand, the direct force applied necessarily ceases as soon as the projectile leaves the hand. The stone, nevertheless, flies on for a certain distance and then falls to the ground. How is this flight of the stone to be explained? The ancient philosophers puzzled more than a little over this problem, and the Aristotelians reached the conclusion that the motion of the hand had imparted a propulsive motion to the air, and that this propulsive motion was transmitted to the stone, pushing it on. Just how the air took on this propulsive property was not explained, and the vagueness of thought that characterized the time did not demand an explanation. Possibly the dying away of ripples in water may have furnished, by analogy, an explanation of the gradual dying out of the impulse which propels the stone.

All of this was, of course, an unfortunate maladbling the pull of gravitation to drag it to the earth earlier than it otherwise could. Were the resistance of the air and the pull of gravitation removed, the stone as projected from the hand would fly on in a straight line, at an unchanged velocity, forever. But this fact, which is expressed in what we now term the first law of motion, was extremely difficult to grasp.

The first important step toward it was perhaps implied in Galileo's study of falling bodies. These studies, as we have seen, demonstrated that a half-pound weight and a hundred-pound weight fall with the same velocity. It is, however, matter of common experience that certain bodies, as, for example, feathers, do not fall at the same rate of speed with these heavier bodies. This anomaly demands an explanation, and the explanation is found in the resistance offered the relatively light object by the air. Once the idea that the air may thus act as an impeding force was grasped, the investigator of mechanical principles had entered on a new and promising course.

Galileo could not demonstrate the retarding influence of air in the way which became familiar a generation or two later; he could not put a feather and a coin in a vacuum tube and prove that the two would there fall with equal velocity, because, in his day, the air-pump had not yet been invented. The experiment was made only a generation after the time of Galileo, as we shall see; but, meantime, the great Italian had fully grasped the idea that atmospheric resistance plays a most important part in regard to the motion of falling and projected bodies. Thanks largely to his own experiments, but partly also to the efforts of others, he had come, before the end of his life, pretty definitely to realize that the motion of a projectile, for example, must be thought of as inherent in the projectile itself, and that the retardation or ultimate cessation of that motion is due to the action of antagonistic forces. In other words, he had come to grasp the meaning of the first law of motion.

It remained, however, for the great Frenchman Descartes to give precise expression to this law two years after Galileo's death. As Descartes expressed it in his *Principia Philosophiæ*, published in 1644, any body once in motion tends to go on in a straight line, at a uniform rate of speed, forever. Contrariwise, a stationary body will remain forever at rest unless acted on by some disturbing force.

This all-important law, which lies at the very foundation of all true conceptions of mechanics, was thus worked out during the first half of the seventeenth century, as the outcome of numberless experiments for which Galileo's experiments with falling bodies furnished the foundation. So numerous and so gradual were the steps by which the reversal of view regarding moving bodies was effected that it is impossible to trace them in detail. We must be content to reflect that at the beginning of the Galilean epoch utterly false notions regarding the subject were entertained by the very greatest philosophers—by Galileo himself for example, and by Kepler—whereas at the close of that epoch the correct and highly illuminative view had been attained.

We must now consider some other experiments of Galileo which led to scarcely less-important results. The experiments in question had to do with the movements of bodies passing down an inclined plane, and with the allied subject of the motion of a pendulum. The elaborate experiments of Galileo regarding the former subject

of a ball rollin

the velocity acquired by a ball was proportional to the height from which the ball descended regardless of the steepness of the incline. Experiments were made also with a ball rolling down a curved gutter, the curve representing the arc of a circle. These experiments led to the study of the curvilinear motions of a weight suspended by a cord; in other words, of the pendulum.

Regarding the motion of the pendulum, some very curious facts were soon ascertained. Galileo found, for example, that a pendulum of a given length performs its oscillations with the same frequency tho the arc described by the pendulum be varied greatly. He found, also, that the rate of oscillation for pendulums of different lengths varies according to a simple law. In order that one pendulum shall oscillate one-half as fast as another, the length of the pendulums must be as four to one. Similarly, by lengthening the pendulums nine times, the oscillation is reduced to one-third. In other words, the rate of oscillation of pendulums varies inversely as the square of their length. Here, then, is a simple relation between the motions of swinging bodies which suggests the relation which Kepler had discovered between the relative motions of the planets.

Every such discovery coming in this age of the rejuvenation of experimental science had a peculiar force in teaching men the all-important lesson that simple laws lie back of most of the diverse phenomena of nature, if only these laws can be discovered.

Galileo further observed that his pendulum might be constructed of any weight sufficiently heavy readily to overcome the atmospheric resistance, and that, with this qualification, neither the weight nor the material had any influence upon the time of oscillation, this being solely determined by the length of the cord. Naturally, the practical utility of these discoveries was not overlooked by Galileo. Since a pendulum of a given length oscillates with unvarying rapidity, here is an obvious means of measuring time. Galileo, however, appears not to have met with any great measure of success in putting this idea into practise. It remained for the mechanical ingenuity of Huygens to construct a satisfactory pendulum clock.

As a theoretical result of the studies of rolling and oscillating bodies, there was developed what is usually spoken of as the third law of motion—namely, the law that a given force operates upon a moving body with an effect proportionate to its effect upon the same body when at rest. Or, as Whewell states the law: "The dynamical effect of force is as the statical effect, that is, the velocity which any force generates in a given time, when it puts the body in motion, is proportional to the pressure which this same force produces in a body at rest."

According to the second law of motion, each one of the different forces, operating at the same time upon a moving body, produces the same effect as if it operated upon the body while at rest.

It appears, then, that the mechanical studies of Galileo, taken as a whole, were nothing less than revolutionary. They constituted the first great advance upon the dynamic studies of Archimedes, and then led to the secure foundation for one of the most important of modern sciences. We shall see that an important company of students entered the field immediately after the time of Galileo, and carried forward the work he had so well begun. But before passing on to the consideration of their labors, we must consider work in allied fields of

d whose

tant than his own. These men are the Dutchman Stevinus, who must always be remembered as a co-laborer with Galileo in the foundation of the science of dynamics, and the Englishman Gilbert, to whom is due the unqualified praise of first subjecting the phenomenon of magnetism to a strictly scientific investigation.

Stevinus was born in 1548 and died in 1620. He was a man of practical genius, and he attracted the attention of his non-scientific contemporaries, among other ways, by the construction of a curious land-craft, which, mounted on wheels, was to be propelled by sails like a boat. Not only did he write a book on this curious horseless carriage, but he put his idea into practical application, producing a vehicle which actually traversed the distance between Scheveningen and Petton, with no fewer than twenty-seven passengers, one of them being Prince Maurice of Orange. This demonstration was made about the year 1600. It does not appear, however, that any important use was made of the strange vehicle; but the man who invented it put his mechanical ingenuity to other use with better effect. It was he who solved the problem of oblique forces, and who discovered the important hydrostatic principle that the pressure of fluids is proportionate to their depth, without regard to the shape of the including vessel.

The study of oblique forces was made by Stevinus with the aid of inclined planes. His most demonstrative experiment was a very simple one, in which a chain of balls of equal weight was hung from a triangle; the triangle being so constructed as to rest on a horizontal base, the oblique sides bearing the relation to each other of two to one. Stevinus found that his chain of balls just balanced when four balls were on the longer side and two on the shorter and steeper side. The balancing of force thus brought about constituted a stable equilibrium, Stevinus being the first to discriminate between such a condition and the unbalanced condition called unstable equilibrium.

By this simple experiment was laid the foundation of the science of statics. Stevinus had a full grasp of the principle which his experiment involved, and he applied it to the solution of oblique forces in all directions. Earlier investigations of Stevinus were published in 1608. His collected works were published at Leyden in 1634.

This study of the equilibrium of pressure of bodies at rest led Stevinus, not unnaturally, to consider the allied subject of the pressure of liquids. He is to be credited with the explanation of the so-called hydrostatic paradox. The familiar modern experiment which illustrates this paradox is made by inserting a long perpendicular tube of small caliber into the top of a tight barrel. On filling the barrel and tube with water, it is possible to produce a pressure which will burst the barrel, tho it be a strong one, and tho the actual weight of water in the tube is comparatively insignificant.

This illustrates the fact that the pressure at the bottom of a column of liquid is proportionate to the height of the column, and not to its bulk, this being the hydrostatic paradox in question. The explanation is that an enclosed fluid under pressure exerts an equal force upon all parts of the circumscribing wall; the aggregate pressure may, therefore, be increased indefinitely by increasing the surface. It is this principle, of course, which is utilized in the familiar hydrostatic press. Theoretical explanations of the pressure of liquids were supplied a generation or two later by numerous investigators, in-science of hydrostatics in modern times dates from the experiments of Stevinus.

Experiments of an allied character, having to do with the equilibrium of fluids, exercised the ingenuity of Galileo. Some of his most interesting experiments have to do with the subject of floating bodies. It will be recalled that Archimedes, away back in the Alexandrian epoch, had solved the most important problems of hydrostatic equilibrium. Now, however, his experiments were overlooked or forgotten, and Galileo was obliged to make experiments anew, and to combat fallacious views that ought long since to have been abandoned.

Perhaps the most illuminative view of the spirit of the times can be gained by quoting at length a paper of Galileo's, in which he details his own experiments with floating bodies and controverts the views of his opponents. The paper has further value as illustrating Galileo's methods both as experimenter and as speculative reasoner.

The current view, which Galileo here undertakes to refute, asserts that water offers resistance to penetration, and that this resistance is instrumental in determining whether a body placed in water will float or sink. Galileo contends that water is non-resistant, and that bodies float or sink in virtue of their respective weights. This, of course, is merely a restatement of the law of Archimedes. But it remains to explain the fact that bodies of a certain shape will float, while bodies of the same material and weight, but of a different shape, will sink. We shall see what explanation Galileo finds of this anomaly as we proceed.

In the first place, Galileo makes a cone of wood or of wax, and shows that when it floats with either its point or its base in the water, it displaces exactly the same amount of fluid, altho the apex is by its shape better adapted to overcome the resistance of the water, if that were the cause of buoyancy. Again, the experiment may be varied by tempering the wax with filings of lead till it sinks in the water, when it will be found that in any figure the same quantity of cork must be added to raise it to the surface.

"But," says Galileo, "this silences not my antagonists; they say that all the discourse hitherto made by me imports little to them, and that it serves their turn; that they have demonstrated in one instance, and in such manner and figure as pleases them best —namely, in a board and in a ball of ebony—that one when put into the water sinks to the bottom, and that the other stays to swim on the top; and the matter being the same, and the two bodies differing in nothing but in figure, they affirm that with all perspicuity they have demonstrated and sensibly manifested what they undertook.

Nevertheless, I believe, and think I can prove, that this very experiment proves nothing against my theory. And first, it is false that the ball sinks and the board not; for the board will sink, too, if you do to both the figures as the words of our question require; that is, if you put them both *in* the water; for to be in the water implies to be placed in the water, and by Aristotle's own definition of place, to be placed imports to be environed by the surface of the ambient body; but when my antagonists show the floating board of ebony, they put it not into the water, but upon the water; where, being detained by a certain impediment (of [illegible] unded artl with water for that was that bodies should be in the water, and not part in the water, part in the air.

"I will not omit another reason, founded also upon experience, and, if I deceive not myself, conclusive against the notion that figure, and the resistance of the water to penetration, have anything to do with the buoyancy of bodies. Choose a piece of wood or other matter, as, for instance, walnut-wood, of which a ball rises from the bottom of the water to the surface more slowly than a ball of ebony of the same size sinks, so that, clearly, the ball of ebony divides the water more readily in sinking than the ball of wood does in rising.

"Then take a board of walnut-tree equal to and like the floating one of my antagonists; and if it be true that this latter floats by reason of the figure being unable to penetrate the water, the other of walnut-tree, without a question, if thrust to the bottom, ought to stay there, as having the same impeding figure, and being less apt to overcome the said resistance of the water. But if we find by experience that not only the thin board, but every other figure of the same walnut-tree, will return to float, as unquestionably we shall, then I must desire my opponents to forbear to attribute the floating of the ebony to the figure of the board, since the resistance of the water is the same in rising as in sinking, and the force of ascension of the walnut-tree is less than the ebony's force for going to the bottom.

"Now let us return to the thin plate of gold or silver, or the thin board of ebony, and let us lay it lightly upon the water, so that it may stay there without sinking, and carefully observe the effect. It will appear clearly that the plates are a considerable matter lower than the surface of the water, which rises up and makes a kind of rampart round them on every side.

"But if it has already penetrated and overcome the continuity of the water, and is of its own nature heavier than the water, why does it not continue to sink, but stop and suspend itself in that little dimple that its weight has made in the water?

"My answer is, because in sinking till its surface is below the water, which rises up in a bank round it, it draws after and carries along with it the air above it, so that that which, in this case, descends in the water is not only the board of ebony or the plate of iron, but a compound of ebony and air, from which composition results a solid no longer specifically heavier than the water, as was the ebony or gold alone.

"But, gentlemen, we want the same matter; you are to alter nothing but the shape, and, therefore, have the goodness to remove this air, which may be done simply by washing the surface of the board, for the water having once got between the board and the air will run together, and the ebony will go to the bottom; and if it does not, you have won the day.

"But methinks I hear some of my antagonists cunningly opposing this, and telling me that they will not on any account allow their boards to be wetted, because the weight of the water so added, by making it heavier than it was before, draws it to the bottom, and that the addition of new weight is contrary to our agreement, which was that the matter should be the same.

"To this I answer, first, that nobody can suppose bodies to be put into the water without their being wet, nor do I wish to do more to the board than you may

1 Moreover it is not true that the board

the washing; for I will put ten or twenty drops on the floating board, and so long as they stand separate it shall not sink; but if the board be taken out and all that water wiped off, and the whole surface bathed with one single drop, and put it again upon the water, there is no question but it will sink, the other water running to cover it, being no longer hindered by the air.

"In the next place, it is altogether false that water can in any way increase the weight of bodies immersed in it, for water has no weight in water, since it does not sink. Now just as he who should say that brass by its own nature sinks, but that when formed into the shape of a kettle it acquires from that figure the virtue of lying in water without sinking, would say what is false, because that is not purely brass which then is put into the water, but a compound of brass and air; so is it neither more nor less false that a thin plate of brass or ebony swims by virtue of its dilated and *broad figure.*

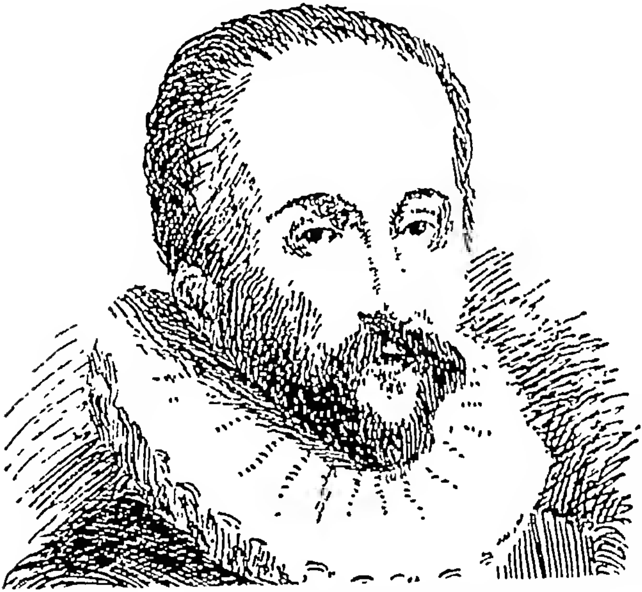
"Also, I cannot omit to tell my opponents that this conceit of refusing to bathe the surface of the board might beget an opinion in a third person of a poverty of argument on their side, especially as the conversation began about flakes of ice, in which it would be simple to require that the surfaces should be kept dry; not to mention that such pieces of ice, whether wet or dry, always float, and so my antagonists say, because of their shape.

"Some may wonder that I affirm this power to be in the air of keeping plate of brass or silver above water, as if in a certain sense I would attribute to the air a kind of magnetic virtue for sustaining heavy bodies with which it is in contact. To satisfy all these doubts I have contrived the following experiment to demonstrate how truly the air does support these bodies; for I have found, when one of these bodies which floats when placed lightly on the water is thoroughly bathed and sunk to the bottom, that by carrying down to it a little air without otherwise touching it in the least, I am able to raise and carry it back to the top, where it floats as before.

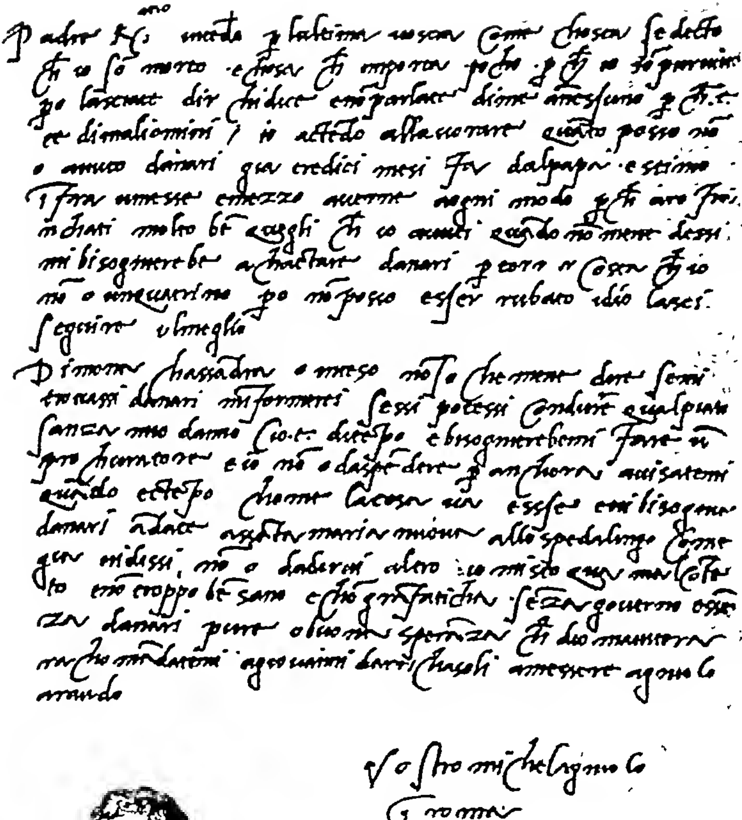
"To this effect, I take a ball of wax, and with a little lead make it just heavy enough to sink very slowly to the bottom, taking care that its surface be quite smooth and even. This, if put gently into the water, submerges almost entirely, there remaining visible only a little of the very top, which, so long as it is joined to the air, keeps the ball afloat; but if we take away the contact of the air by wetting this top, the ball sinks to the bottom and remains there. Now to make it return to the surface by virtue of the air which before sustained it, thrust into the water a glass with the mouth downward, which will carry with it the air it contains, and move this down toward the ball until you see, by the transparency of the glass, that the air has reached the top of it; then gently draw the glass upward, and you will see the ball rise, and afterwards stay on the top of the water, if you carefully part the glass and water without too much disturbing it."

It will be seen that Galileo, while holding in the main to a correct thesis, yet mingles with it some false ideas. At the very outset, of course, it is not true that water has no resistance to penetration; it is true, however, in the sense in which Galileo uses the term—that is to say, the resistance of the water to penetration is not the determining factor ordinarily in decidin whether body it is not altogether inappropriate to say that the water resists penetration and thus supports the body. The modern physicist explains the phenomenon as due to surface-tension of the fluid.

Of course, Galileo's disquisition on the mixing of air with the floating body is utterly fanciful. His experiments were beautifully exact; his theorizing from them was, in this instance, altogether fallacious. Thus, as already intimated, his paper is admirably adapted to convey a double lesson to the student of science.



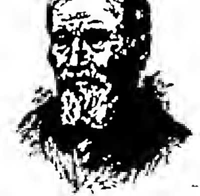
JAN LIPPERSHEY, INVENTOR OF THE TELESCOPE

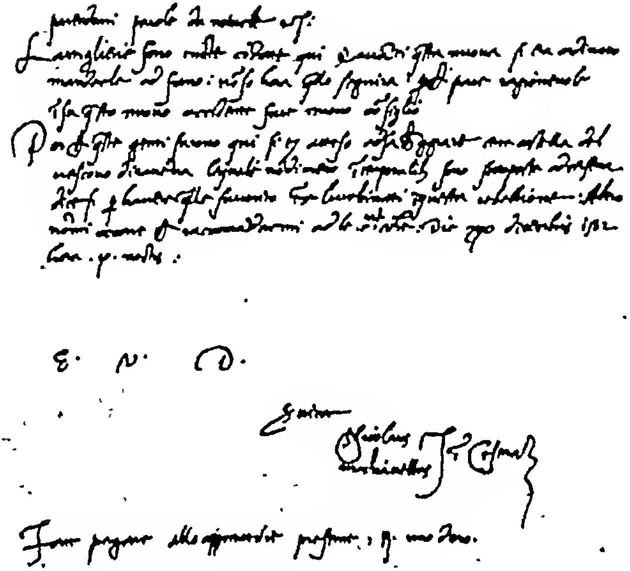


Padre k^mo intedo p lultima vostra come chosta se decto chio so morto e chosa chi importa pocho p chio so pur vivo po lasciategli dir e nõ parlate di me a nessuno p che ce de maligni omini io actēdo allavorare quāto posso nō o avuto danari gia tredici mesi fa dal papa e stimo i fra un mese e mezzo averne a ogni modo p chi arò fatti e spesi molto bē quegli chio o avuti quādo nō me ne dessi mi bisognerebbe achactar danari p tornar costa chio nō o un quactrino po nō posso esser rubato idio lasci seguire el meglio

Di simone chassadra e meso nō so che me ne dire senō trovassi danari minformerei sessi potessi condurre qualque cosa sanza mio danno co.t. decte po e bisognerebbemi fare un procuratore e io nō o da spēdere p anchora avisatemi quādo e tempo che me la cosa a essere e mi bisogna danari a dare a sancta maria nuova allo spedalingo come gia vi dissi nō o a darvi altro io mi sto qua mal contento e nō troppo bē sano e cho gran fatica sanza governo e sanza danari pure o buona sperāza chi dio maiuterà racchomandatemi a giovanni da ricchasoli a messere agnolo araldo

vostro michelagniolo
i roma





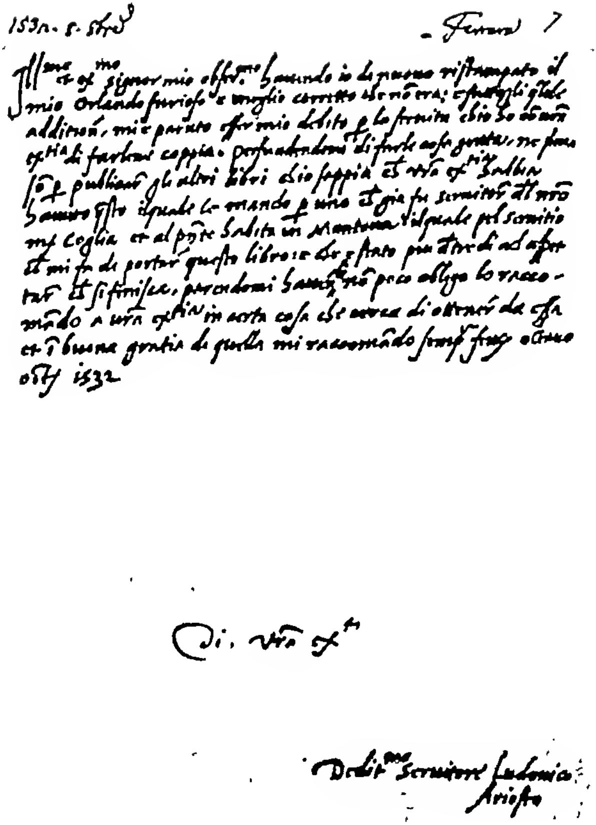
E. N. D.

Servitor
Nicolaus
machiavellus

MACHIAVELLI

Date, 1502-1508.

British Museum, Egerton MS. 23

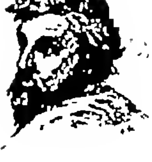


1532 · 8 · 8bre — Ferrara 7

Ill.mo et ecc.mo Signor mio oss.mo havendo io di nuovo ristampato il mio Orlando furioso e meglio corretto che non era; e postogli qualche additione, mi è paruto per mio debito per la servitù ch'io ho con v.ra ecc.tia di farlene copia. persuadendomi di farle cosa grata, ne prima se publicano gli altri libri ch'io sappia che v.ra ecc.tia habbia havuto questo il quale le mando per uno che già fu servitore del nostro m. Coglia et al presente habita in Mantova il quale pel servitio che mi fa de portar questo libro e che è stato più di tre di ad aspettar che si finisse, parendomi havere non poco obligo lo raccomando a v.ra ecc.tia in certa cosa che cerca di ottener da essa et in buona gratia di quella mi raccomando sempre. Ferrara ottavo ott. 1532

Di V.ra Ecc.tia

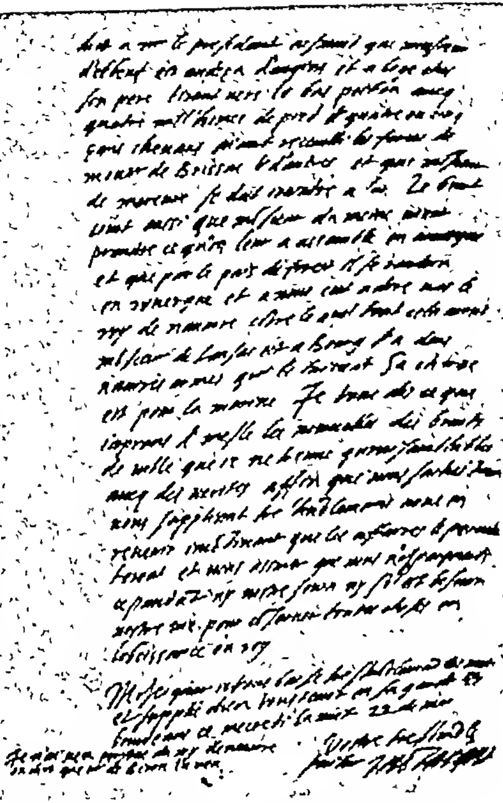
Deditissimo Servitore Ludovico Ariosto



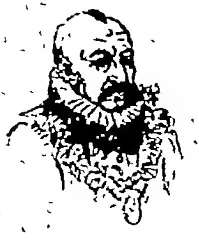
LUDOVICO ARIOSTO

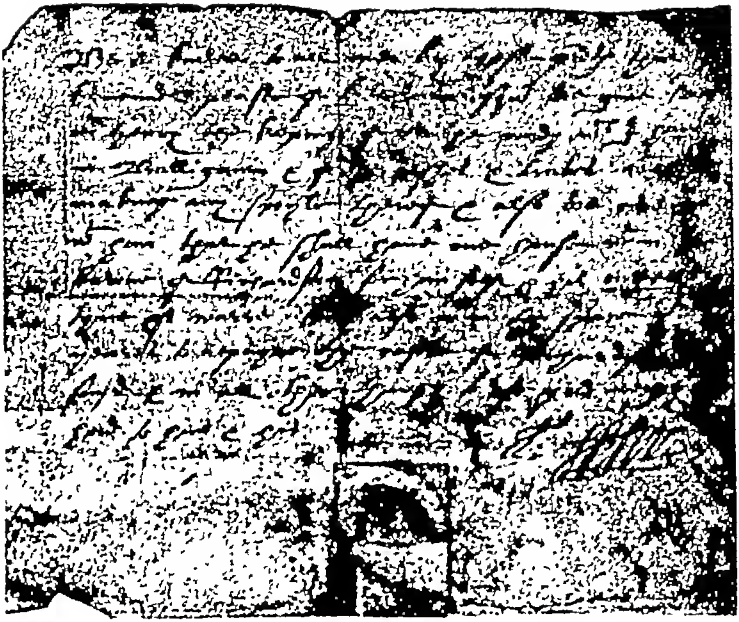
Date, 1532

British Museum Egerton MS 2013



MICHEL DE MONTAIGNE.
June, 1585.
(British Museum, Egerton MS. 23.)

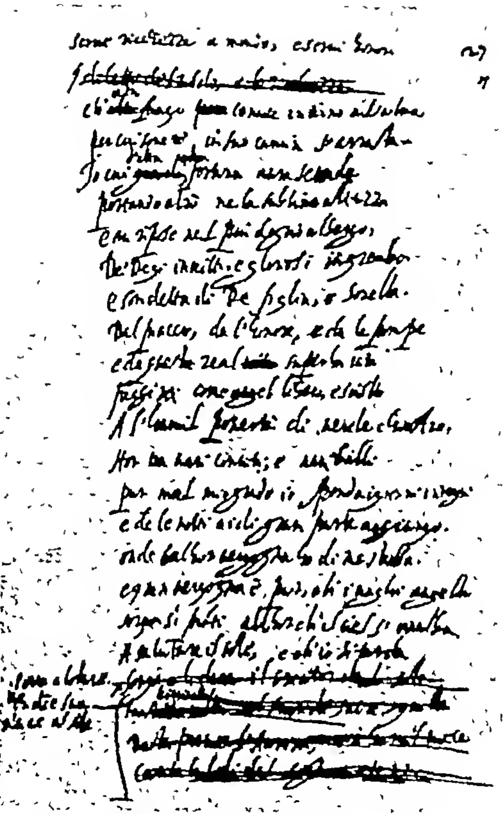




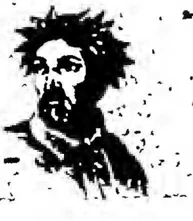
EDMUND SPENSER.

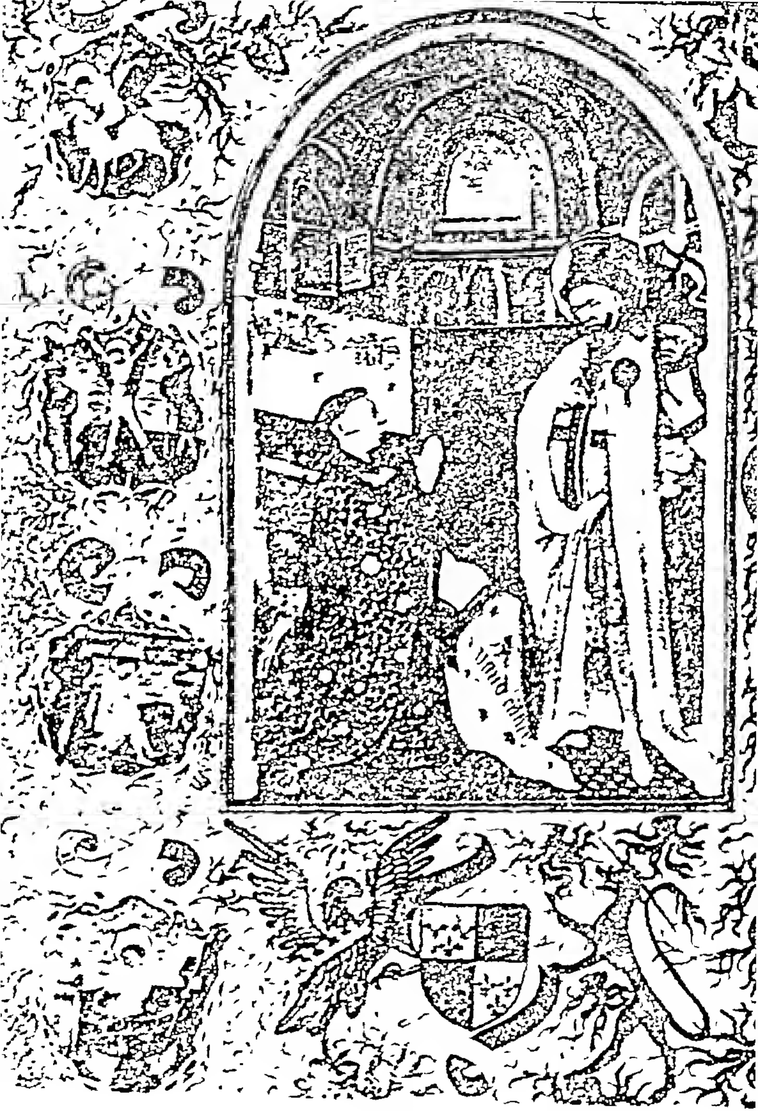
Date, about 1591.

British Museum, Add. MS. 19,869.



TORQUATO TASSO.
Born, 1544; died, 1595.
British Museum, Add. MS. [illegible]

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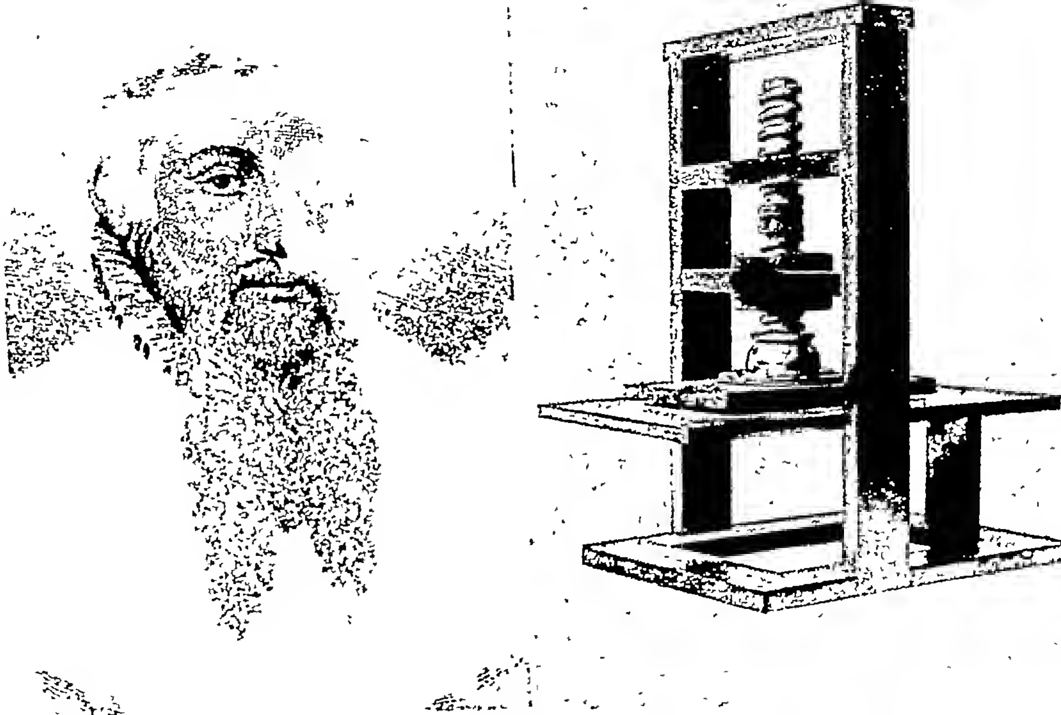
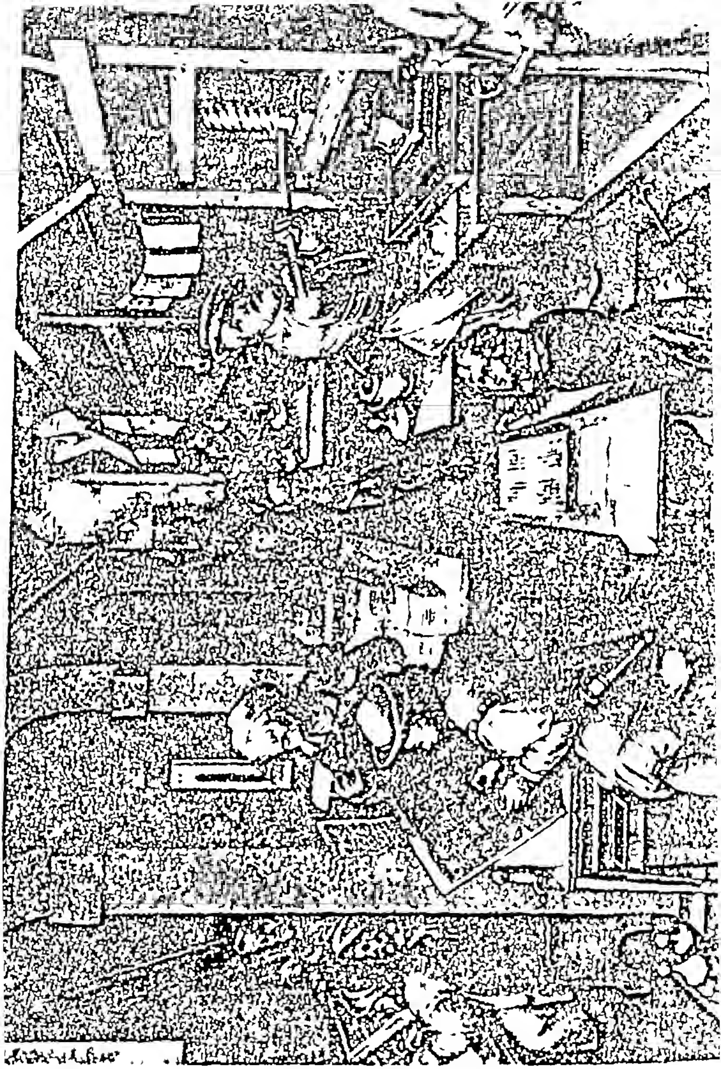


GUTENBERG AND HIS PRESS



PRINT SHOP OF JOHANNES STRADANUS

VII

WILLIAM GILBERT AND THE STUDY OF MAGNETISM

IT will be observed that the studies of Galileo and Stevinus were chiefly concerned with the force of gravitation. Meanwhile, there was an English philosopher of corresponding genius, whose attention was directed toward investigation of the equally mysterious force of terrestrial magnetism. With the doubtful exception of Bacon, Gilbert was the most distinguished man of science in England during the reign of Queen Elizabeth. He was for many years court physician, and Queen Elizabeth ultimately settled upon him a pension that enabled him to continue his researches in pure science.

His investigations in chemistry, altho supposed to be of great importance, are mostly lost; but his great work, *De Magnete*, on which he labored for upwards of eighteen years, is a work of sufficient importance, as Hallam says, "to raise a lasting reputation for its author." From its first appearance it created a profound impression upon the learned men of the Continent, altho in England Gilbert's theories seem to have been somewhat less favorably received Galileo freely expressed his admiration for the work and its author; Bacon, who admired the author, did not express the same admiration for his theories; but Dr. Priestley, later, declared him to be "the father of modern electricity."

Strangely enough, Gilbert's book had never been translated into English, or apparently into any other language, until recent years, altho at the time of its publication certain learned men, unable to read the book in the original, had asked that it should be. By this neglect or oversight a great number of general readers as well as many scientists, through succeeding centuries, have been deprived of the benefit of writings that contained a good share of the fundamental facts about magnetism as known today.

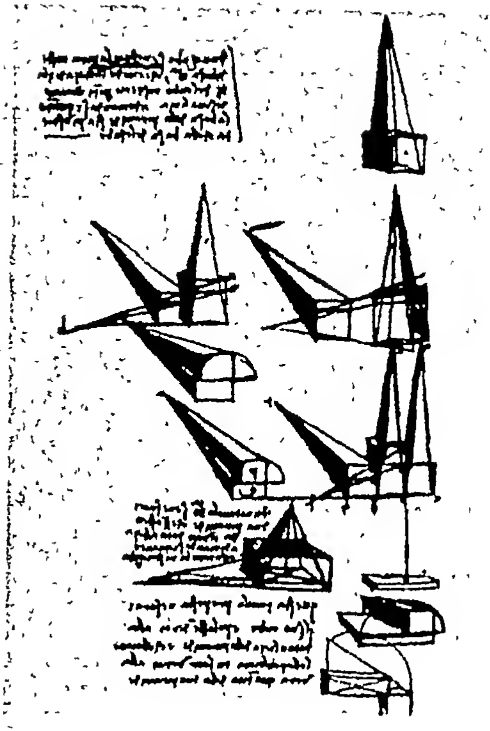
Gilbert was the first to discover that the earth is a great magnet, and he not only gave the name of "pole" to the extremities of the magnetic needle, but also spoke of these "*poles*" as north and *south pole*, altho he used these names in the opposite sense from that in which we now use them, his south pole being the extremity which pointed toward the north, and vice versa. He was also first to make use of the terms "electric force," "electric emanations," and "electric attractions."

It is hardly necessary to say that some of the views taken by Gilbert, many of his theories, and the deductions from some of his experiments have in recent times been found to be erroneous. As a pioneer in an unexplored field of science, however, his work is remarkably accurate. "On the whole," says Dr. John Robinson, "this performance contains more real information than any writing of the age in which he lived, and is scarcely exceeded by any that has appeared since."

In the preface to his work Gilbert says: "Since in the discovery of secret things, and in the investigation of hidden causes, stronger reasons are obtained from sure experiments and demonstrated arguments than from probable conjectures and the opinions of philosophical speculators of the common sort, therefore, to the end of that noble substance of that great lodestone, our common mother (the earth), still quite unknown, and also that the forces extraordinary and exalted of this globe may the better be understood, we have decided, first, to begin with the common stony and ferruginous matter, and magnetic bodies, and the part of the earth that we may handle and may perceive with senses, and then to proceed with plain magnetic experiments, and to penetrate to the inner parts of the earth."

Before taking up the demonstration that the earth is simply a giant lodestone, Gilbert demonstrated in an ingenious way that every lodestone, of whatever size, has definite and fixed poles. He did this by placing the stone in a metal lathe and converting it into a sphere, and upon this sphere demonstrated how the poles can be found. To this round lodestone he gave the name of *terrella*—that is, little earth.

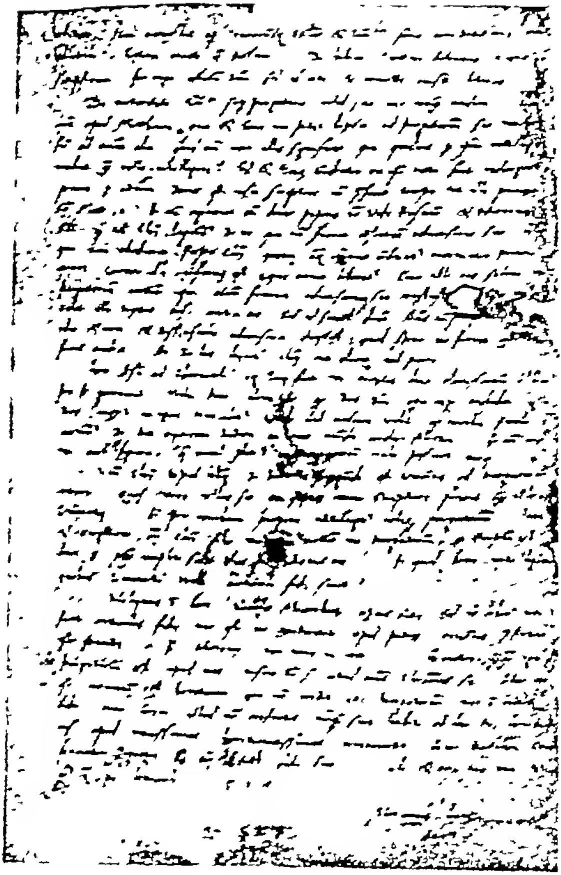
"To find, then, poles answering to the earth," he says, "take in your hand the round stone, and lay on it a needle or a piece of iron wire: the ends of the wire move round their middle point, and suddenly come to a standstill. Now, with ochre or with chalk, mark where the wire lies still and sticks. Then move the middle or center of the wire to another spot, and so to a third and fourth, always marking the stone along the length of the wire where it stands still; the lines so marked will exhibit meridian circles, or circles like meridians, on the stone or terrella; and manifestly they will all come together at the poles of the stone. The circle being continued in this way, the poles appear, both the north and the south, and betwixt these, mid-



LEONARDO DA VINCI

Date, about 1508

British Museum, Arundel MS. 263.



MARTIN LUTHER

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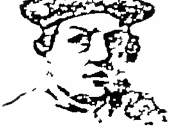


way, we may draw a large circle for an equator, as is done by the astronomer in the heavens and on his spheres, and by the geographer on the terrestrial globe."

Gilbert had tried the familiar experiment of placing the lodestone on a float in water, and observed that the poles always revolved until they pointed north and south, which he explained as due to the earth's magnetic attraction. In this same connection he noticed that a piece of wrought iron mounted on a cork float was attracted by other metals to a slight degree, and he observed also that an ordinary iron bar, if suspended horizontally by a thread, assumes invariably a north and south direction. These, with many other experiments of a similar nature, convinced him that the earth "is a magnet and a lodestone," which he says is a "new and till now unheard-of view of the earth."

Fully to appreciate Gilbert's revolutionary views concerning the earth as a magnet, it should be remembered that numberless theories to explain the action of the electric needle had been advanced. Columbus and Paracelsus, for example, believed that the magnet was attracted by some point in the heavens, such as a magnetic star. Gilbert himself tells of some of the beliefs that had been held by his predecessors, many of whom he declares "wilfully falsify." One of his first steps was to refute by experiment such assertions as that of Cardan, that "a wound by a magnetized needle was painless"; and also the assertion of Fracastoni that lodestone attracts silver; or that of Scalinger, that the diamond will attract iron; and the statement of Matthiolus that "iron rubbed with garlic is no longer attracted to the lodestone."

Gilbert made extensive experiments to explain the dipping of the needle, which had been first noticed by William Norman. His deduction as to this phenomenon led him to believe that this was also explained by the magnetic attraction of the earth, and to predict where the vertical dip would be found. These deductions seem the more wonderful because at the time he made them the dip had just been discovered, and had not been studied except at London. His theory of the dip was, therefore, a scientific prediction, based on a preconceived hypothesis.

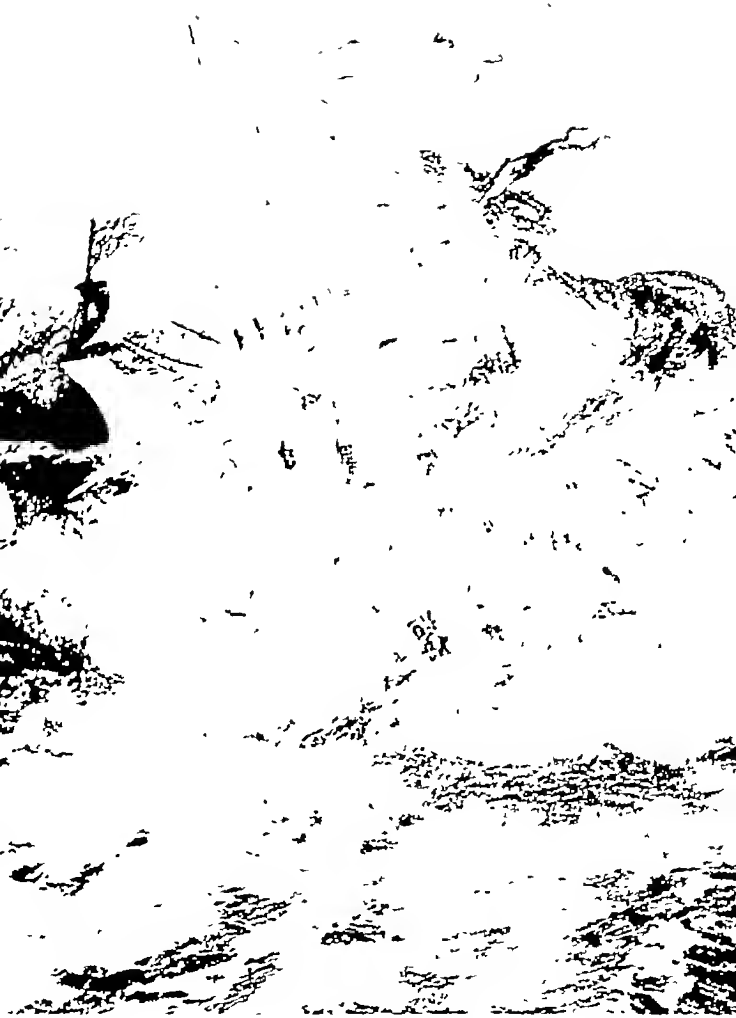
Gilbert found the dip to be 72° at London; eight years later Hudson found the dip at 75° 22′ north latitude to be 89° 30′; but it was not until over two hundred years later, in 1831, that the vertical dip was first observed by Sir James Ross at about 70° 5′ north latitude, and 96° 43′ west longitude. This was not the exact point assumed by Gilbert, and his scientific predictions, therfore, were not quite correct; but such comparatively slight and excusable errors mar but little the excellence of his work as a whole.

A brief epitome of some of his other important discoveries suffices to show that the exalted position in science accorded him by contemporaries, as well as succeeding generations of scientists, was well merited. He was first to distinguish between magnetism and electricity, giving the latter its name. He discovered also the "electrical charge," and pointed the way to the discovery of insulation by showing that the charge could be retained some time in the excited body by covering it with some non-conducting substance, such as silk; altho, of course, electrical conduction can hardly be said to have been more than vaguely surmised, if understood at all by him.

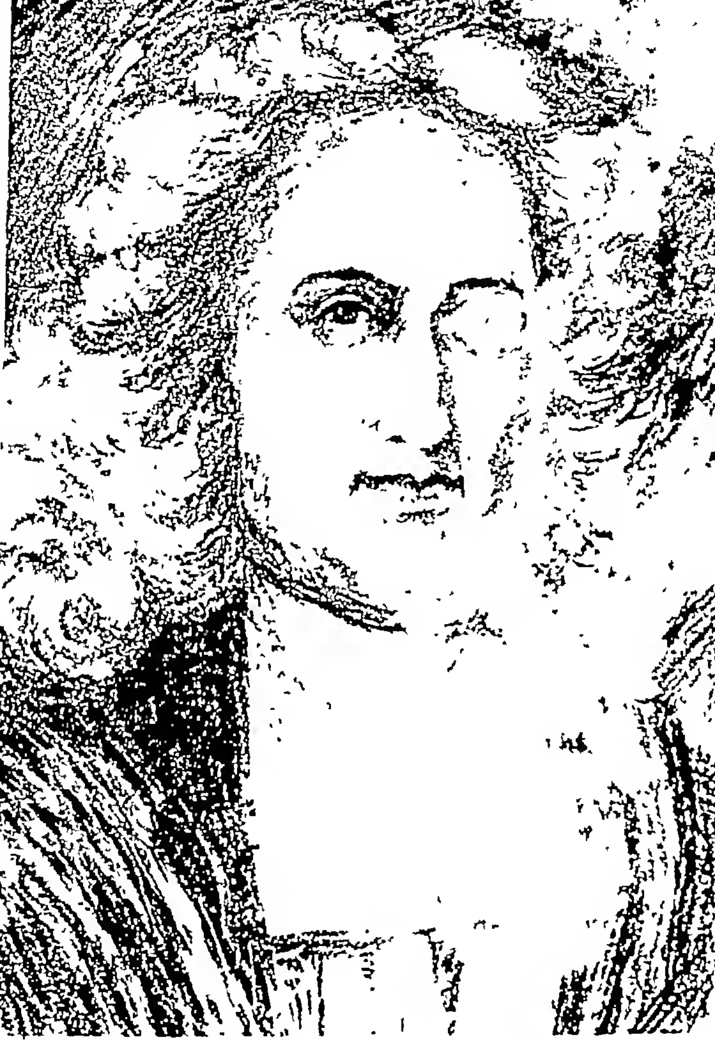
The first electrical instrument ever made, and known as such, was invented by him, as was also the first magnetometer, and the first electrical indicating device. Altho three centuries have elapsed since his death, the method of magnetizing iron first introduced by him is in common use today.

He made exhaustive experiments with a needle balanced on a pivot to see how many substances he could find which, like amber, on being rubbed affected the needle. In this way he discovered that light substances were attracted by alum, mica, arsenic, sealing-wax, lac sulfur, slags, beryl, amethyst, rock-crystal, sapphire, jet, carbuncle, diamond, opal, Bristol stone, glass, glass of antimony, gum-mastic, hard resin, rock-salt, and, of course, amber. He discovered also that atmospheric conditions affected the production of electricity, dryness being unfavorable and moisture favorable.

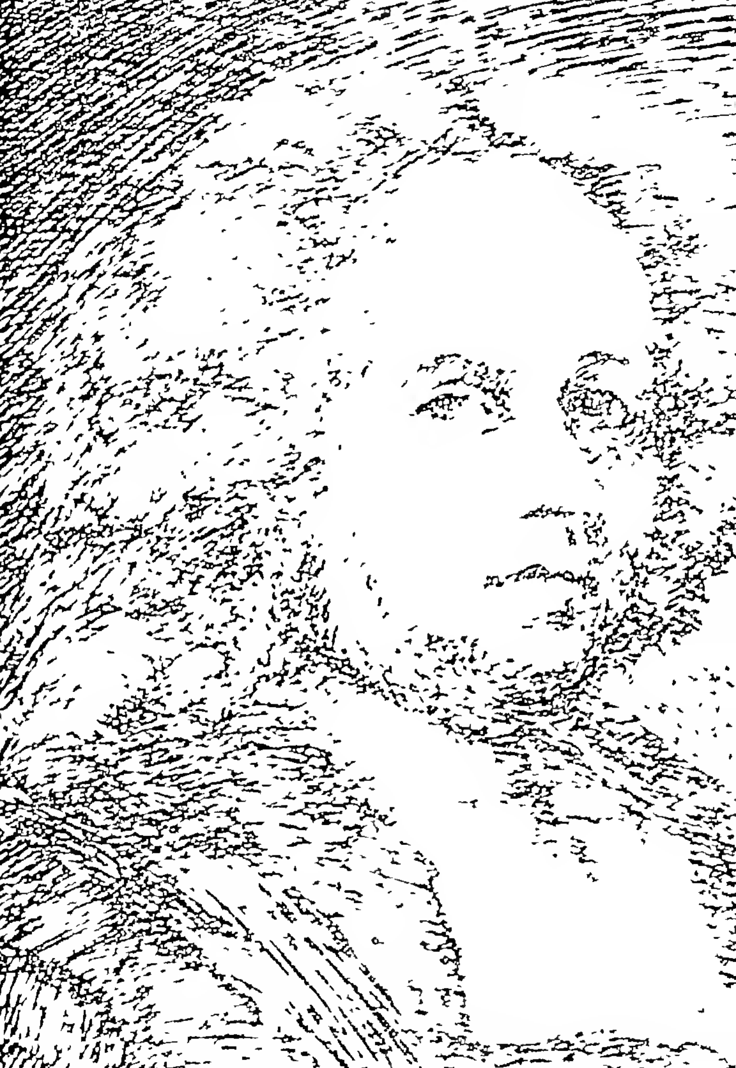
Galileo's estimate of this first electrician is the verdict of succeeding generations. "I extremely admire and envy this author," he said. "I think him worthy of the greatest praise for the many new and true observations which he has made, to the disgrace of so many vain and fabling authors."

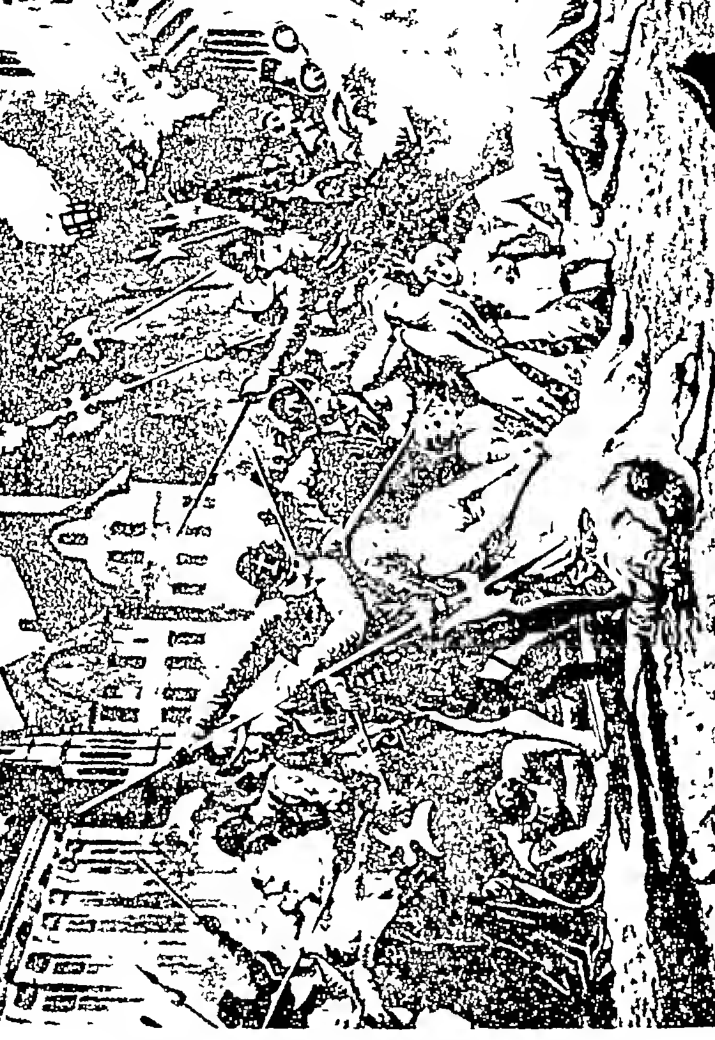


SPANISH ARMADA

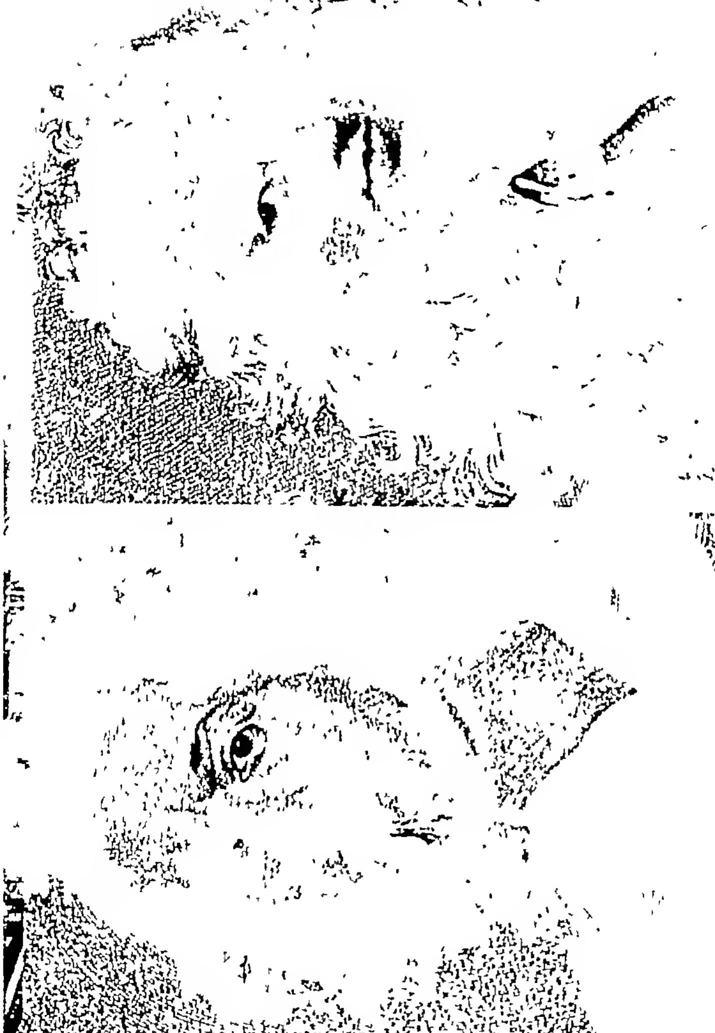


EDMUND HALLEY, WHO DEBUNKED THE COMET
(1656-1742)





CELEBRATING ST BARTHOLOMEW'S NIGHT



VON GUERRICKE AND HUYGENS

VIII

STUDIES OF LIGHT, HEAT, AND ATMOSPHERIC PRESSURE

WE have seen that Gilbert was by no means lacking in versatility, yet the investigations upon which his fame is founded were all pursued along one line, so that the father of magnetism may be considered one of the earliest of specialists in physical science. Most workers of the time, on the other hand, extended their investigations in many directions.

The sum total of scientific knowledge of that day had not bulked so large as to exclude the possibility that one man might master it all. So we find a Galileo, for example, making revolutionary discoveries in astronomy, and performing fundamental experiments in various fields of physics. Galileo's great contemporary, Kepler, was almost equally versatile, tho his astronomical studies were of such preeminent importance that his other investigations sink into relative insignificance. Yet he performed some notable experiments in at least one department of physics. These experiments had to do with the refraction of light, a subject which Kepler was led to investigate, in part at least, through his interest in the telescope.

We have seen that Ptolemy in the Alexandrian time, and Alhazen, the Arab, made studies of refraction. Kepler repeated their experiments, and, striving as always to generalize his observations, he attempted to find the law that governed the observed change of direction which a ray of light assumes in passing from one medium to another. Kepler measured the angle of refraction by means of a simple yet ingenious trough-like apparatus which enabled him to compare readily the direct and refracted rays. He discovered that when a ray of light passes through a glass plate, if it strikes the farther surface of the glass at an angle greater than 45° it will be totally refracted instead of passing through into the air. He could not well fail to know that different mediums refract light differently, and that for the same medium the amount of light varies with the change in the angle of incidence. He was not able, however, to generalize his observations as he desired, and to the last the law that governs refraction escaped him.

It remained for Willebrord Snell, a Dutchman, about the year 1621, to discover the law in question, and for Descartes, a little later, to formulate it. Descartes, indeed, has sometimes been supposed to be the discoverer of the law. There is reason to believe that he based his generalizations on the experiment of Snell, tho he did not openly acknowledge his indebtedness.

The law, as Descartes expressed it, states that the sine of the angle of incidence bears a fixed ratio to the sine of the angle of refraction for any given medium. Here, then, was another illustration of the fact that almost infinitely varied phenomena may be brought within the scope of a simple law. Once the law had been expressed, it could be tested and verified with the greatest ease; and, as usual, the discovery being made, it seems surprizing that earlier investigators—in particular so sagacious a guesser as Kepler—should have missed it.

Galileo himself must have been to some extent a student of light, since, as we have seen, he made such notable contributions to practical optics through perfecting the telescope; but he seems not to have added anything to the theory of light. The subject of heat, however, attracted his attention in a somewhat different way, and he was led to the invention of the first contrivance for measuring temperatures. His thermometer was based on the afterwards familiar principle of the expansion of a liquid under the influence of heat; but as a practical means of measuring temperature it was a very crude affair, because the tube that contained the measuring liquid was exposed to the air, hence barometric changes of pressure vitiated the experiment.

It remained for Galileo's Italian successors of the Accademia del Cimento of Florence to improve upon the apparatus, after the experiments of Torricelli—to which we shall refer in a moment—had thrown new light on the question of atmospheric pressure. Still later the celebrated Huygens hit upon the idea of using the melting and the boiling point of water as fixed points in a scale of measurements, which first gave definiteness to thermometric tests.

In the closing years of his life Galileo took into his family, as his adopted disciple in science, a young man, Evangelista Torricelli (1608-1647), who proved himself, during his short lifetime, to be a worthy follower of his great master. Not only worthy on account of his great scientific discoveries, but grateful as well, for when he had made the great discovery that the "suction" made by a vacuum was really nothing but air pressure, and not suction at all, he regretted that so important a step in science might not have been made by his great teacher, Galileo, instead of by himself.

"This generosity of Torricelli," says Playfair, "was perhaps rarer than his genius: there are more who might have discovered the suspension of mercury in the barometer than who would have been willing to part with the honor of the discovery to a master or a friend."

Torricelli's discovery was made in 1643, less than two years after the death of his master. Galileo had observed that water will not rise in an exhausted tube, such as a pump, to a height greater than thirty-three feet, but he was never able to offer a satisfactory explanation of the principle. Torricelli was able to demonstrate that the height at which the water stood depended upon nothing but its weight as compared with the weight of air. If this be true, it is evident that any fluid will be supported at a definite height, according to its relative weight as compared with air.

Thus mercury, which is about thirteen times more dense than water, should only rise to one-thirteenth the height of a column of water—that is, about thirty inches. Reasoning in this way, Torricelli proceeded to prove that his theory was correct. Filling a long tube, closed at one end, with mercury, he inverted the tube with its open orifice in a vessel of mercury. The column of mercury fell at once, but at a height of about thirty inches it stopped and remained stationary, the pressure of the air on the mercury in the vessel maintaining it at that height.

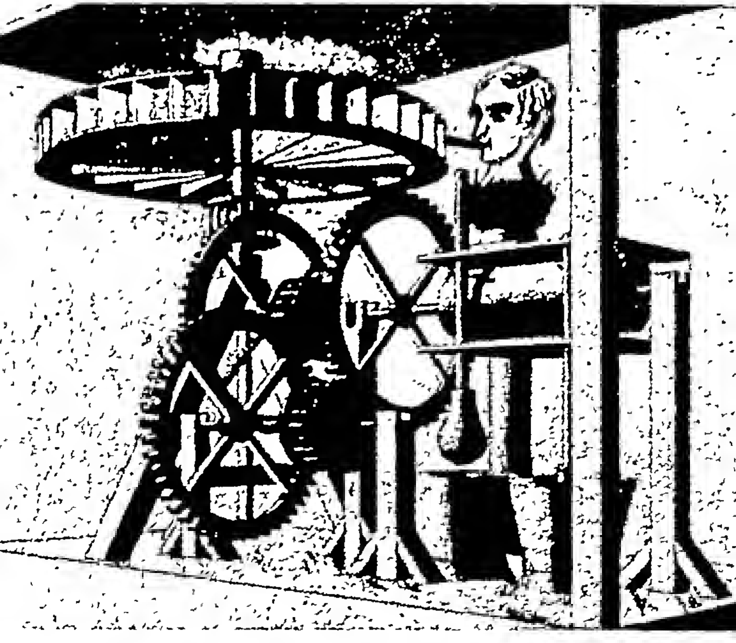
This discovery was a shattering blow to the old theory that had dominated that field of physics for so many centuries. It was completely revolutionary to prove that, instead of a mysterious something within the tube being responsible for the suspension of liquids at certain heights, it was simply the ordinary atmos-

pheric pressure—mysterious enough, it is true — pushing upon them from without. The pressure exerted by the atmosphere was but little understood at that time, but Torricelli's discovery aided materially in solving the mystery. The whole class of similar phenomena of air pressure, which had been held in the trammel of long-established but false doctrines, was now reduced to one simple law, and the door to a solution of a host of unsolved problems thrown open.

It had long been suspected and believed that the density of the atmosphere varies at certain times. That the air is sometimes "heavy" and at other times "light" is apparent to the senses without scientific apparatus for demonstration. It is evident, then, that *Torricelli's column of mercury should rise* and *fall just* in proportion to the lightness or heaviness of the air. A short series of observations proved that it did so, and with those observations went naturally the observations as to changes in the weather. It was only necessary, therefore, to scratch a scale on the glass tube, indicating relative atmospheric pressures, and the Torricellian barometer was complete.

Such a revolutionary theory and such an important discovery were, of course, not to be accepted without controversy, but the feeble arguments of the opponents showed how untenable the old theory had become. In 1648 Pascal suggested that if the theory of the pressure of air upon the mercury was correct, it could be demonstrated by ascending a mountain with the mercury tube. As the air was known to get progressively lighter from base to summit, the height of the column should be progressively lessened as the ascent was made, and increase again on the descent into the denser air. The experiment was made on the mountain called the Puyde-Dôme, in Auvergne, and the column of mercury fell and rose progressively through a space of about three inches as the ascent and descent were made.

This experiment practically sealed the verdict on the new theory, but it also suggested something more. If the mercury descended to a certain mark on the scale on a mountain-top whose height was known, why was not this a means of measuring the heights of all other elevations? And so the beginning was made which, with certain modifications and corrections in details, is now the basis of barometrical measurements of heights.



EARLY MODEL OF STEAM ENGINE

IX

ON THE TRACK OF THE STEAM ENGINE

IT will be recalled that Hero of Alexandria produced—or at least described and so is credited with producing, tho the actual inventor may have been Ctesibius—a little toy mechanism, in which a hollow ball was made to revolve on an axis through the agency of steam, which escaped from two bent tubes placed on opposite sides of the ball, their orifices pointing in opposite directions. The apparatus had no practical utility, but it sufficed to establish the principle that heat, acting through the agency of steam, could be made to do mechanical work.

No other worker continued the experiments, so far as is known, until the time of the great Italian, Leonardo da Vinci, who, late in the fifteenth century, gave a new impulse to mechanical invention. Leonardo experimented with steam, and succeeded in producing what was virtually an explosion engine, by the agency of which a ball was propelled along the earth. But this experiment also failed to have practical result.

Such sporadic experiments as these have no sequential connection with the story of the evolution of the steam engine. The experiments which led directly on to practical achievements were not begun until the seventeenth century. In the very first year of that century, an Italian named Giovanni Battista della Porta published a treatise on pneumatics, in which the idea of utilizing steam for the purpose of raising water was expressly stated.

The idea of this inventor was put into effect in 1624 by a French engineer and mathematician, Solomon de Caus. He invented two different machines, the first of which required a spherical boiler having an internal tube reaching nearly to the bottom; a fire beneath the boiler produced steam which would force the water in the boiler to a height proportional to the pressure obtained.

In the other machine, steam is led from the boiler into the upper part of a closed cistern containing water to be elevated. To the lower portion of the cistern a delivery pipe was attached so that water was discharged under a considerable pressure. This arrangement was precisely similar to the apparatus employed by Hero of Alexandria in various of his fountains, as regards the principle of expanding gas to propel water. An important difference, however, consists in the fact that the scheme of della Porta and of de Caus embodied the idea of generating pressure with the aid of steam, whereas Hero had depended merely on the expansive property of air compressed by the water itself.

While these mechanisms contained the germ of an idea of vast importance, the mechanisms themselves were of trivial utility. It is not even clear whether their projectors had an idea of the properties of the condensation of vapor, upon which the working of the practical steam engine so largely depends. This idea, however, was probably grasped about half a century later by an Englishman, Edward Somerset, the celebrated Marquis of Worcester, who in 1663 described in his *Century of Inventions* an apparatus for raising water by the expansive force of steam. His own account of his invention is as follows:

"An admirable and most forcible way to drive up water by fire: not by drawing or sucking it upwards, for that must be as the philosopher calleth it, *intra sphæram activitatis*, which is but at such a distance. But this way hath no bounder, if the vessel be strong enough: for I have taken a piece of whole cannon, whereof the end was burst, and filled it three-quarters full of water, stopping and screwing up the broken end, as also the touch-hole; and making a constant fire under it, within twenty-four hours it burst and made a great crack; so that having a way to make my vessels so that they are strengthened by the force within them, and the one to fill after the other, I have seen the water run like a constant stream, forty feet high: one vessel of water, rarefied by fire, driveth up forty of cold water; and the man that tends the work is but to turn two cocks, that one vessel of water being consumed, another begins to force and refill with cold water, and so successively; the fire being tended and kept constant, which the self-same person may likewise abundantly perform in the interim, between the necessity of turning the said cocks."

It is unfortunate that the Marquis did not give a more elaborate description of this remarkable contrivance. The fact that he treats it so casually is sufficient evidence that he had no conception of the possibilities of the mechanism; but, on the other hand, his description suffices to prove that he had gained a clear notion of, and had experimentally demonstrated, the tremendous power of expansion that resides in steam. No example of his steam pump has been preserved, and historians of the subject have been left in doubt as to some details of its construction, and in particular as to whether it utilized the principle of a vacuum created through condensation of the steam.

This principle was clearly grasped, however, by another Englishman, Thomas Savery, a Cornish mine captain, who in 1698 secured a patent for a steam engine to be applied to the raising of water, etc. A working model of this machine was produced before the Royal Society in 1699. The transactions of the Society contain the following: "June 14th, 1699, Mr. Savery entertained the Royal Society with showing a small model of his engine for raising water by help of fire, which he set to work before them: the experiment succeeded according to expectation, and to their satisfaction."

The following very clear description of Savery's engine is given in the introduction to Beckmann's *History of Inventions*:

"This engine, which was used for some time to a considerable extent for raising water from mines, consisted of a strong iron vessel shaped like an egg, with a tube or pipe at the bottom, which descended to the place from which the water was to be drawn, and another at the top, which ascended to the place to which it was to be elevated.

"This oval vessel was filled with steam supplied from a boiler, by which the atmospheric air was first blown out of it. When the air was thus expelled and nothing but pure steam left in the vessel, the communication with the boiler was cut off, and cold water poured on the external surface. The steam within was thus condensed and a vacuum produced, and the water drawn up from below in the usual way by suction. The oval vessel was thus filled with water; a cock placed at the bottom of the lower pipe was then closed, and steam was introduced from the boiler into the oval vessel above the surface of the water. This steam being of high pressure, forced the water up the ascending tube, from the top of which it was discharged, and the oval vessel being thus refilled with steam, the vacuum was again produced by condensation, and the same process was repeated.

"By using two oval steam vessels, which would act alternately—one drawing water from below, while the other was forcing it upwards, an uninterrupted discharge of water was produced. Owing to the danger of explosion, from the high pressure of the steam which was used, and from the enormous waste of heat by unnecessary condensation, these engines soon fell into disuse."

This description makes it obvious that Savery had the clearest conception of the production of a vacuum by the condensation of steam, and of the utilization of the suction thus established (which suction, as we know, is really due to the pressure of outside air) to accomplish useful work. Savery also arranged this apparatus in duplicate, so that one vessel was filling with water while the other was forcing water to the delivery pipe. This is credited with being the first useful apparatus for raising water by the combustion of fuel. There was a great waste of steam, through imparting heat to the water, but the feasibility of the all-important principle of accomplishing mechanical labor with the aid of heat was at last demonstrated.

As yet, however, the experimenters were not on the track of the method by which power could be advantageously transferred to outside machinery. An effort in quite another direction to accomplish this had been made as early as 1629 by Giovanni Branca, an Italian mathematician, who had proposed to obtain rotary motion by allowing a jet of steam to blow against the vanes of a fan wheel, capable of turning on an axis. In other words, he endeavored to utilize the principle of the windmill, the steam taking the place of moving air.

The idea is of course perfectly feasible, being indeed virtually that which is employed in the modern steam turbine; but to put the idea into practise requires special detailed arrangements of steam jet and vanes, which it is not strange the early inventor failed to discover. His experiments appear not to have been followed up by any immediate successor, and nothing practical came of them, nor was the principle which he had attempted to utilize made available until long after a form of steam engine utilizing another principle for the transmission of power had been perfected.

The principle in question was that of causing expanding steam to press against a piston working tightly in a cylinder, a principle, in short, with which everyone is familiar nowadays through its utilization in the ordinary steam engine. The idea of making use of such a piston appears to have originated with a Frenchman, Denis Papin, a scientific worker, who, being banished from his own country, was established as professor of mathematics at the University of Marburg. He conceived the important idea of transmitting power by means of a piston as early as 1688, and about two years later added the idea of producing a vacuum in a cylinder, by cooling the cylinder,—the latter idea being, as we have just seen, the one which Savery put into effect.

It will be noted that Papin's invention antedated that of Savery; to the Frenchman, therefore, must be given the credit of hitting upon two important principles which made feasible the modern steam engine. Papin constructed a model consisting of a small cylinder in which a solid piston worked. In the cylinder beneath the piston was placed a small quantity of water, which, when the cylinder was heated, was turned into steam, the elastic force of which raised the piston. The cylinder was then cooled by removing the fire, when the steam condensed, thus creating a vacuum in the cylinder, into which the piston was forced by the pressure of the atmosphere.

Such an apparatus seems crude enough, yet it incorporates the essential principles, and required but the use of ingenuity in elaborating details of the mechanism, to make a really efficient steam engine. It would appear, however, that Papin was chiefly interested in the theoretical, rather than in the really practical side of the question, and there is no evidence of his having produced a working machine of practical power, until after such machines worked by steam had been constructed elsewhere.

As has happened so often in other fields, Englishmen were the first to make practical use of the new ideas. In 1705 Thomas Newcomen, a blacksmith or ironmonger, and John Cawley, a plumber and glazier, patented their atmospheric engine, and five years later, in the year 1710, namely, Newcomen had on the market an engine which is described in the *Report of the Department of Science and Arts of the South Kensington Museum,* as "the first real pumping engine ever made."

The same report describes the engine as "a vertical steam cylinder provided with a piston connected at one end of the beam, having a pivot or bearing in the middle of its length, and at the other end of the beam pump rods for working the pump. The cylinder was surrounded by a second cylinder or jacket, open at the top, and cold water could be supplied to this outer cylinder at pleasure. The single or working cylinder could be supplied with steam when desired from a boiler below it. There was a drain pipe from the bottom of the working cylinder, and one from the outer cylinder."

The report continues: "For the working of the engine steam was admitted to the working cylinder, so as to fill it and expel all the air, the piston then being at the top, owing to the weight of the pump rods being sufficient to lift it; then the steam was shut off and the drain cocks closed and cold water admitted to the outer cylinder, so that the steam in the working cylinder condensed, and, leaving a partial vacuum of pressure of the atmosphere, forced the piston down and drew up the pump rods, thus making a stroke of the pump. Then the water was drawn off from the outer cylinder and steam admitted to the working cylinder before allowing the piston to return to the top of its stroke, ready for the next down stroke."

It will be observed that this machine adopts the principle, with only a change of mechanical details, of the Papin engine just described. A later improvement made by Newcomen did away with the outer cylinder for condensing the steam, employing instead an injection of cold water into the working cylinder itself, thus enabling the engine to work more quickly. It is said that the superiority of the internal condensing arrangement was accidentally discovered through the improved working of an engine that chanced to have an exceptionally leaky piston or cylinder. Many engines were made on this plan and put into practical use.

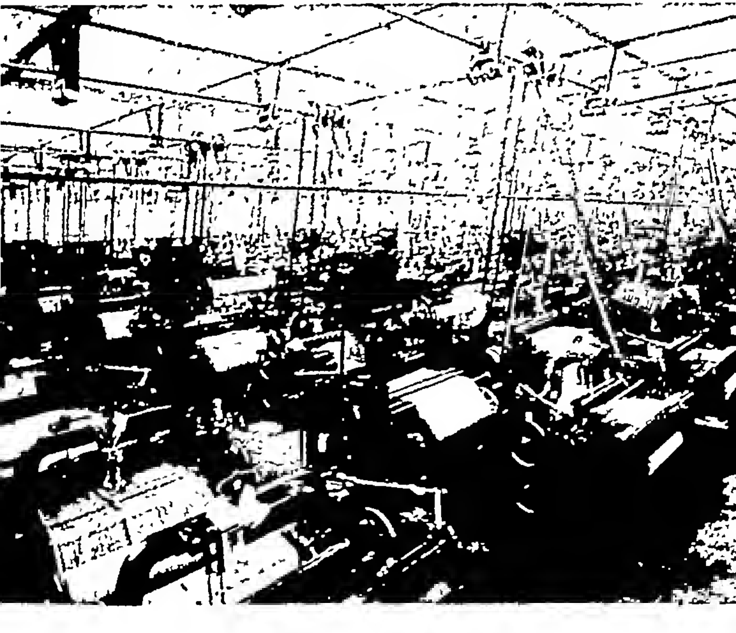
Another important improvement was made by a connection from the beam to the cocks or valves, so that the engine worked automatically, whereas in the first place it had been necessary to have a boy or man operate the valves—a most awkward arrangement, in the light of modern improvements. As the story is told, the duty of opening and closing the regulating and condensing valves was intrusted to boys called cock boys. It is said that one of these boys named Humphrey Potter "wishing to join his comrades at play without exposing himself to the consequences of suspending the performance of the engine, contrived, by attaching strings of proper length to the levers which governed the two cocks, to connect them with the beam, so that it should open and close the cocks as it moved up and down with the most perfect regularity."

This story has passed current for almost two centuries, and it has been used to point many a useful moral. It seems almost a pity to disturb so interesting a tradition yet it must have occurred to more than one iconoclast that the tale is almost too good to be true. And somewhat recently it has been more than hinted that Desaguliers, with whom the story originated, drew upon his imagination for it.

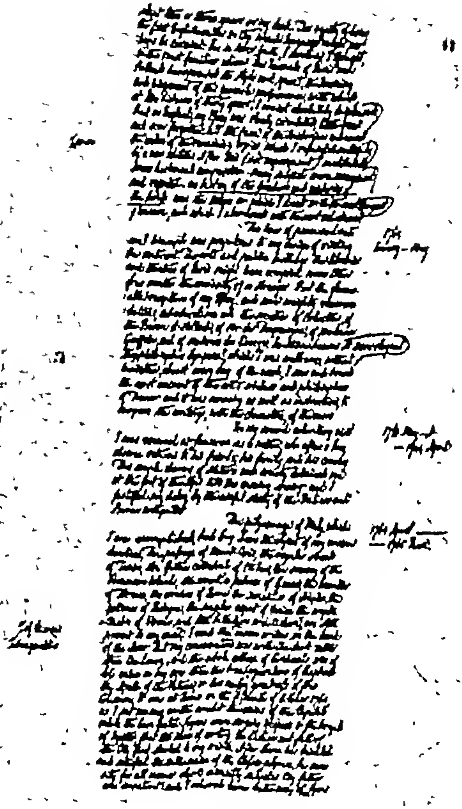
A print is in existence, made so long ago as 1719, representing an engine erected by Newcomen at Dudley Castle, Staffordshire, in 1712, in which an automatic valve gear is clearly shown, proving that the Newcomen engine was worked automatically at this early period. That the admirable story of the inventive youth, whose wits gave him leisure for play, may not be altogether discredited, however, it should be added that unquestionably some of the early engines had a hand-moved gear, and that at least one such was still working in England after the middle of the nineteenth century.

It seems probable, then, that the very first engines were without the automatic valve gear, and there is no inherent reason why a quick-witted youth may not have been the first to discover and remedy the defect.

According to the *Report of the Department of Science and Arts of the South Kensington Museum*: "The adoption of Newcomen's engine was rapid, for, commencing in 1711 with the engine at Wolverhampton, of twenty-three-inch diameter and six-feet stroke, they were in common use in English collieries in 1725; and Smeaton found in 1767 that, in the neighborhood of Newcastle alone there were fifty-seven at work, ranging in size from twenty-eight-inch to seventy-five-inch cylinder diameter, and giving collectively about twelve hundred horse-power. As Newcomen obtained an evaporation of nearly eight pounds of water per pound of coal, the increase of boiler efficiency since his time has necessarily been but slight, altho in other requisities of the steam generator great improvements are noticeable."



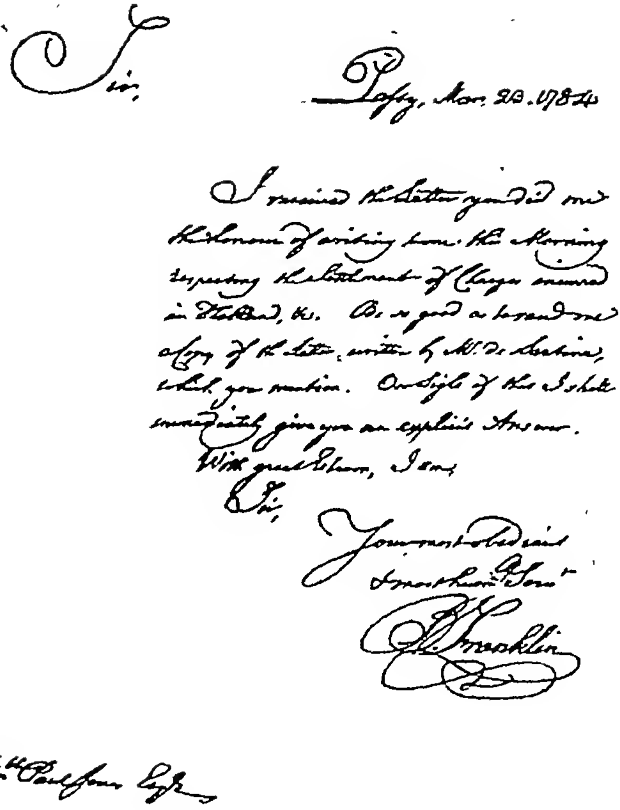
COTTON MILL



EDWARD GIBBON

Born 1737 died 1794

British Museum Add. MS. 34,874



Sir,

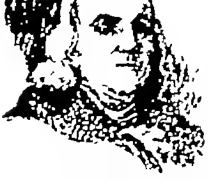
Passy, Nov. 23. 1784

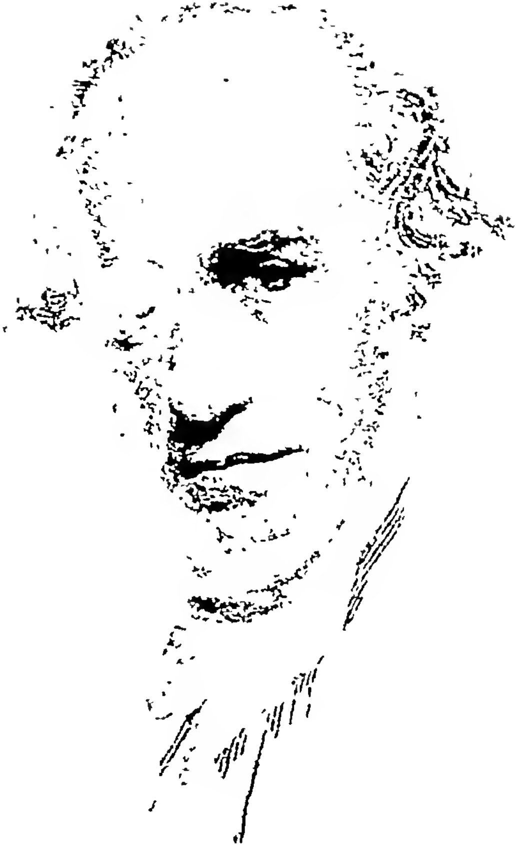
I received the Letter you did me the Honour of writing to me this Morning respecting the Settlement of Charges incurred in Holland, &c. Be so good as to send me a Copy of the Letter, written by M. de Castries, which you mention. On Sight of this I shall immediately give you an explicit Answer.

With great Esteem, I am,
Sir,
Your most obedient
& most humble Servt
B. Franklin

Honble Paul Jones Esqr

BENJAMIN FRANKLIN
Date 1784
British Museum, Add MS. 21,506





JAMES WATT

LIBRARY

THE COMING OF JAMES WATT

THE Newcomen engine had low working efficiency as compared with the modern engine; nevertheless, some of these engines are still used in a few collieries where waste coal is available, the pressure enabling the steam to be generated in boilers unsafe for other purposes. The great importance of the Newcomen engine, however, is historical; for it was while engaged in repairing a model of one of these engines that James Watt was led to invent his plan of condensing the steam, not in the working cylinder itself, but in a separate vessel—the principle upon which such vast improvements in the steam engine were to depend.

It is impossible to overestimate the importance of the work which Watt accomplished in developing the steam engine. Fully to appreciate it, we must understand that up to this time the steam engine had a very limited sphere of usefulness. The Newcomen engine represented the most developed form, as we have seen; and this, like the others that it had so largely superseded, was employed solely for the pumping of water. In the main, its use was confined to mines, which were often rendered unworkable because of flooding.

We have already seen that a considerable number of engines were in use, yet their power in the aggregate added but a trifle to man's working efficiency, and the work that they did accomplish was done in a most uneconomical manner. Indeed the amount of fuel required was so great as to prohibit their use in many mines, which would have been valuable could a cheaper means have been found of freeing them from water. Watt's inventions, as we shall see, accomplished this end, as well as various others that were not anticipated.

It was through consideration of the wasteful manner of action of the steam engine that Watt was led to give attention to the subject. The great inventor was a young man at the University of Glasgow. He had previously served an apprenticeship of one year with a maker of philosophical instruments in London, but ill health had prevented him from finishing his apprenticeship, and he had therefore been prohibited from practising his would-be profession in Glasgow Finally, however, he had been permitted to work under the auspices of the university; and in due course, as a part of his official duties, he was engaged in repairing a model of the Newcomen engine. This incident is usually mentioned as having determined the line of Watt's future activity.

It should be recalled, however, that Watt had become a personal friend of the celebrated Professor Black, the discoverer of latent heat, and the foremost authority in the world, in this period, on the study of pneumatics. Just what share Black had in developing Watt's idea, or in directing his studies toward the expansive properties of steam, it would perhaps be difficult to say. It is known, however, that the subject was often under discussion; and the interest evinced in it·by Black is shown by the fact that he subsequently wrote a history of Watt's inventions.

It is never possible, perhaps, for even the inventor himself to re-live the history of the growth of an idea in his own mind. Much less is it possible for him to say precisely what share of his progress has been due to chance suggestions of others. But it is interesting, at least, to recall this association of Watt with the greatest experimenter of his age in a closely allied field. Questions of suggestion aside, it illustrates the technical quality of Watt's mind, making it obvious that he was no mere ingenious mechanic, who stumbled upon his invention. He was, in point of fact, a carefully trained scientific experimenter, fully equipped with all the special knowledge of his time in its application to the particular branch of pneumatics to which he gave attention.

The first and most obvious defect in the Newcomen engine was, as Watt discovered, that the alternating cooling and heating of the cylinder resulted in an unavoidable waste of energy. The apparatus worked, it will be recalled, by the introduction of steam into a vertical cylinder beneath the piston, the cylinder being open above the piston to admit the air. The piston rod connected with a beam suspended in the middle, which operated the pump, and which was weighted at one end in order to facilitate the raising of the piston. The steam, introduced under low pressure, scarcely more than counteracted the pressure of the air, the raising of the piston being largely accomplished by the weight in question.

Of course the introduction of the steam heated the cylinder. In order to condense the steam and produce a vacuum, water was injected, the cylinder being thereby cooled. A vacuum being thus produced beneath the cylinder, the pressure of the air from above thrust the cylinder down, this being the actual working agent. It was for this reason that the Newcomen engine was called, with much propriety, a pneumatic engine. Its action was very slow, and it was necessary to employ a very large piston in order to gain a considerable power.

WASHINGTON

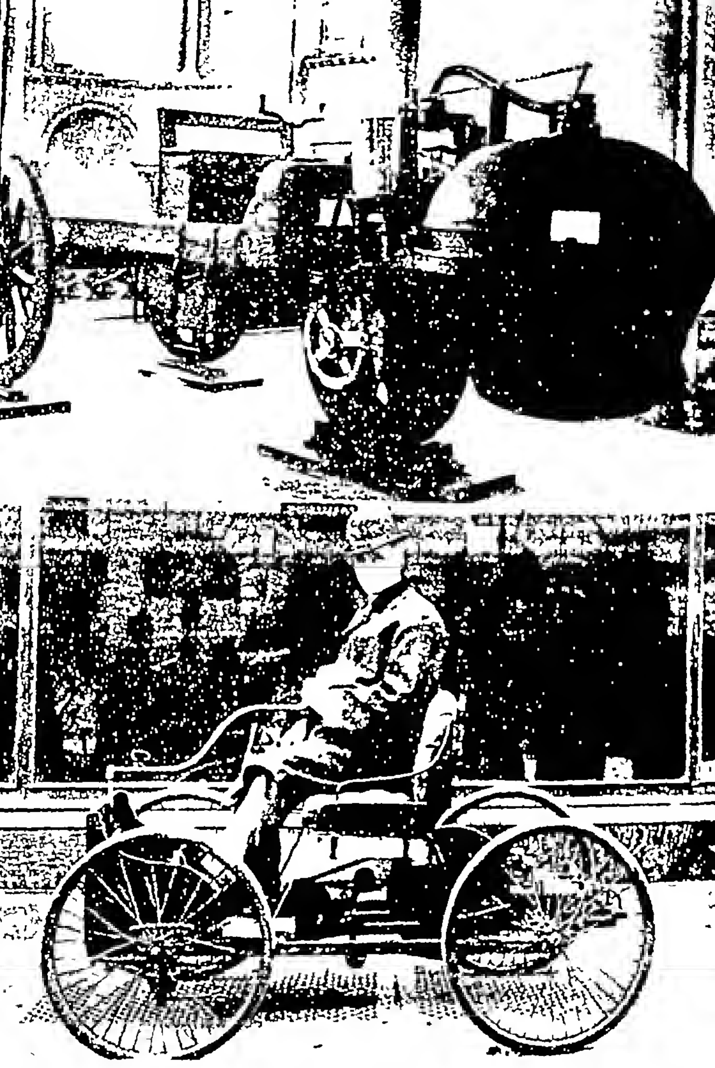
The first idea that occurred to Watt in connection with the probable improvement of this mechanism did not look to the alteration of any of the general features of the structure, as regards size or arrangement of cylinder, piston, or beam, or the essential principle upon which the engine worked. His entire attention was fixed on the discovery of a method by which the loss of heat through periodical cooling of the cylinder could be avoided. We are told that he contemplated the subject long, and experimented much, before he reached a satisfactory solution.

Naturally enough his attention was first directed toward the cylinder itself. He queried whether the cylinder might not be made of wood, which, through its poor conduction of heat, might better equalize the temperature. Experiments in this direction, however, produced no satisfactory result.

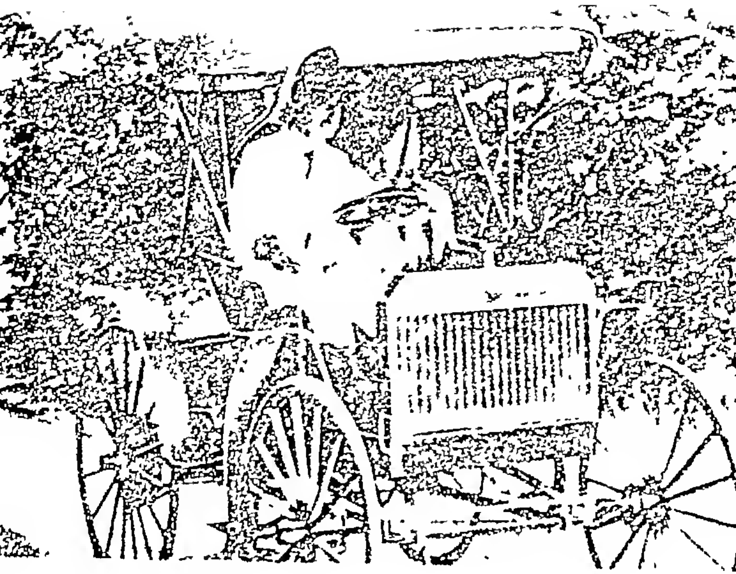
Then at last an inspiration came to him. Why not connect the cylinder with another receptacle, in which the condensation of the steam could be effected?

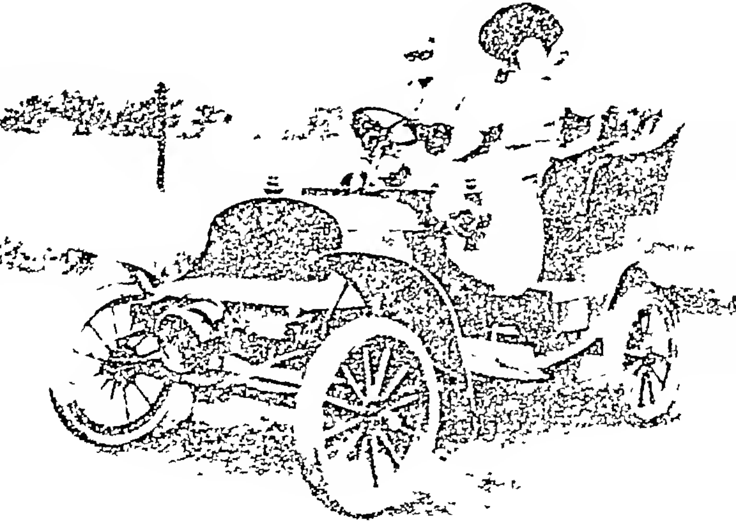
The idea was a brilliant one, but neither its originator nor any other man of the period could possibly have realized its vast and all-comprehending importance. For in that idea was contained the germ of all the future of steam as a motive power. Indeed, it scarcely suffices to speak of it as the germ merely; the thing itself was there, requiring only the elaboration of details to bring it to perfection.

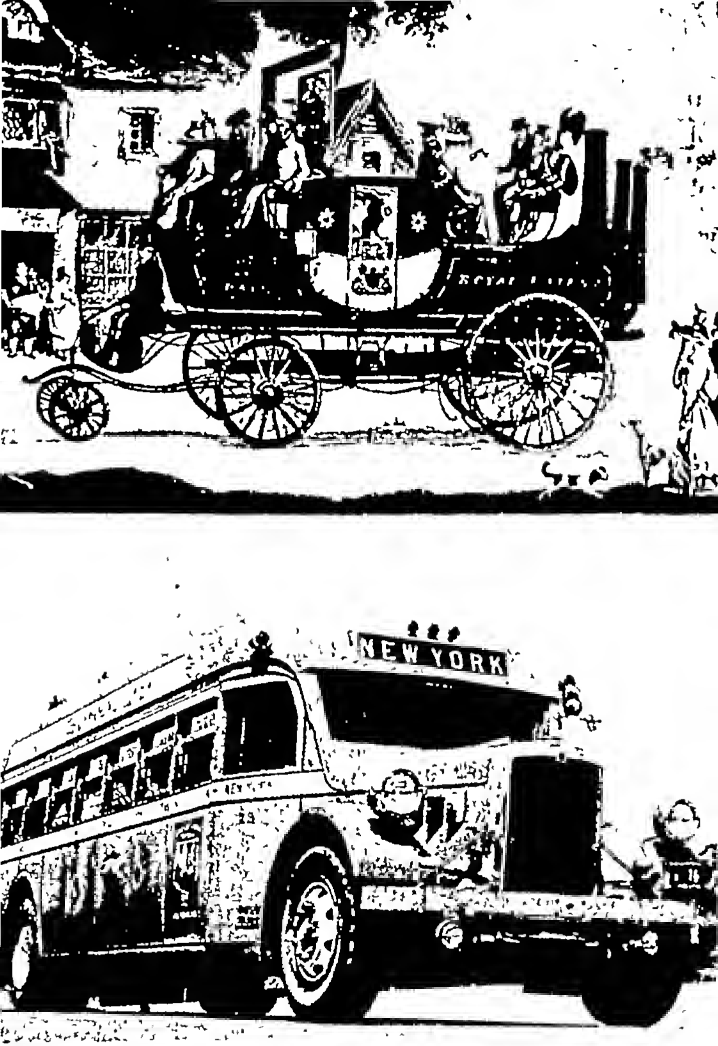
Watt immediately set to work to put his brilliant conception of the separate condenser to the test of experiment. He connected the cylinder of a Newcomen engine with a receptacle into which the steam could be discharged after doing its work on the piston. The receptacle was kept constantly cooled by a jet of water,



HORSELESS CARRIAGES OF THE







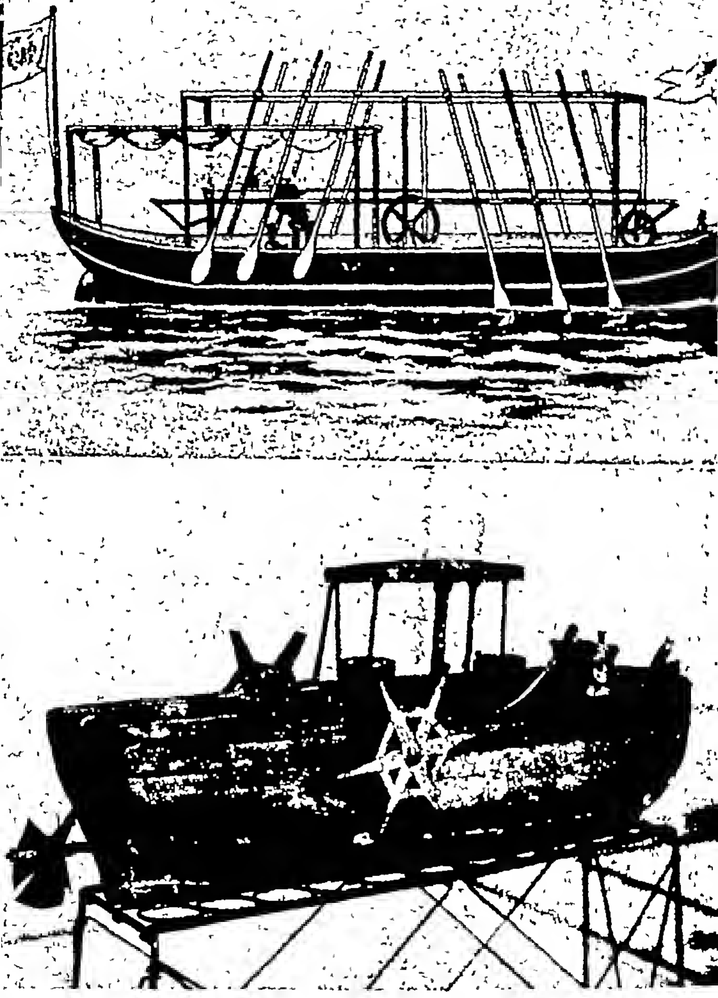
LONDON, 1820—NEW YORK, TODAY

this water and the water of condensation, together with any air or uncondensed steam that might remain in the receptacle, being constantly removed with the aid of an air pump. The apparatus at once demonstrated its practical efficiency—and the modern steam engine had come into existence.

It was in the year 1765, when Watt was twenty-nine years old, that he made his first revolutionary experiment, but his first patents were not taken out until 1769, by which time his engine had attained a relatively high degree of perfection.

It must be understood that Watt's engine was at first used exclusively as an apparatus for pumping. For some time there was no practical attempt to apply the mechanism to any other purpose. That it might be so applied, however, was soon manifest, in consideration of the relative speed with which the piston now acted. It was not until 1781, however, that Watt's second patent was taken out, in which devices are described calculated to convert the reciprocating motion of the piston into motion of rotation, in order that the engine might drive ordinary machinery.

It seems to be conceded that Watt was himself the originator of the idea of making the application through the medium of a crank and fly-wheel such as are now universally employed. But the year before Watt took out his second patent, another inventor named James Picard had patented this device of crank and connecting rod, having, it is alleged, obtained the idea from a workman in Watt's employ. Whatever be the truth as to this point, Picard's patent made it necessary for Watt to find some alternative device, and after experimenting, he hit upon the so-called sun and planet gearing, and henceforth this was used on his rotary engines until the time



JOHN FITCH'S STEAMBOATS

for the expiration of Picard's patent, after which the simpler and more satisfactory crank and fly-wheel were adopted.

In the meantime, Watt had associated himself with a business partner named Boulton, under the firm name of Boulton and Watt. In 1776 a special act of legislation extending the term of Watt's original patent for a period of twenty-five years had been secured. All infringements were vigorously prosecuted, and the inventor, it is gratifying to reflect, shared fully in the monetary proceeds that accrued from his invention.

Notwithstanding the early recognition of the possibility of securing rotary motion with Watt's perfected Newcomen engine, it was long before the full possibilities of the application of this principle were realized, even by the most practical of machinists. Watt himself apparently appreciated the possibilities no more fully than the others, as the use of his famous engines "Beelzebub" and "Old Bess" in the establishment of Boulton and Watt amply testifies.

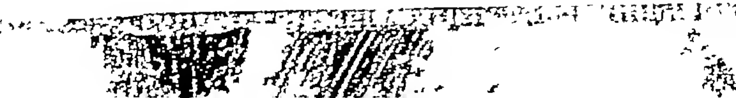
It appears that Boulton had been an extensive manufacturer of ornamental metal articles. To drive his machinery at Soho he employed two large water wheels, twenty-four feet in diameter and six feet wide. These sufficed for his purpose under ordinary conditions, but in dry weather from six to ten horses were required to aid in driving the machinery. When Watt's perfected engine was available, however, this was utilized to pump water from the tail race back to the head race, that it might be used over and over.

"Old Bess" had a cylinder thirty-three inches in diameter with seven-foot stroke, operating a pump twenty-four inches in diameter; it therefore had remarkable efficiency as a pumping apparatus. But of course it utilized, at best, only a portion of the working energy contained in the steam; and the water wheels in turn could utilize not more than fifty per cent of the store of energy which the pump transferred to the water in raising it. Therefore, such use of the steam engine involved a most wasteful expenditure of energy.

It was long, however, before the practical machinists could be made to believe that the securing of direct rotary power from the piston could be satisfactorily accomplished. It was only after the introduction of higher speed and heavier fly-wheels, together with improved governors, that the speed of rotation was so equalized as to meet satisfactorily the requirements of the practical engineer, and ultimately to displace the wasteful method of securing rotary motion indirectly through the aid of pump and water wheel.

It may be added that the centrifugal governor, with which modern engines are provided to regulate their speed, was the invention of Watt himself.

In the year 1782 Watt took out patents which contained specifications for the two additional improvements that constituted his final contribution to the production of the steam engine. The first of these provided for the connection of the cylinder chamber on each side of the piston with the condenser, so that the engine became double acting. The second introduced the very important principle—from the standpoint of economy in the use of steam—of shutting off the supply of steam from the cylinder while the piston has only partially traversed its thrust, and allowing the remainder of the thrust to be accomplished through the expansion of the steam. The application of the first of these principles obviously adds greatly to the efficiency of the engine, and in practise it was found that the application of the second principle



produces a very great saving in steam, and thus adds materially to the economical working of the engine.

All of Watt's engines continued to make use of the walking beam attached to the piston for the transmission of power; and engineers were very slow indeed to recognize the fact that in many—in fact in most—cases this contrivance may advantageously be done away with. The recognition of this fact constitutes one of the three really important advances that have been made in the steam engine since the time of Watt. The other two advances consist of the utilization of steam under high pressure and the introduction of the principle of the compound engine.

Neither of these ideas was unknown to Watt, since the utilization of steam under high pressure was advocated by his contemporary, Trevithick, while the compound engine was invented by another contemporary named Hornblower. Perhaps the very fact that these rival inventors put forward the ideas in question may have influenced Watt to antagonize them; in particular since his firm came into legal conflict with each of the other inventors. At any rate, Watt continued to the end of his life to be an ardent advocate of low pressure for the steam engine, and his firm even attempted to have laws passed making it illegal—on the ground of danger to human life—to utilize high-pressure steam, such as employed by Trevithick.

Possibly the conservatism of increasing age may also have had its share in rendering Watt antagonistic to the new ideas; for he was similarly antagonistic to the idea of applying steam to the purpose of locomotion. Trevithick, among others, had made such application with astonishing success, producing a steam automobile which traversed the highway successfully. In his earlier years

Watt had conceived the same idea, and had openly expressed his opinion that the steam engine might be used for this purpose. But late in life he was so antipathetic to the idea that he is said to have put a clause in the lease of his house, providing that no steam carriage should under any pretext be allowed to approach it.

These incidents have importance as showing—as we shall see illustrated again and again in other fields—the disastrous influence in retarding progress that may be exercised by even the greatest of scientific discoverers, when authority well earned in earlier years is exercised in an unfortunate direction later in life. But such incidents as these are inconsequential in determining the position among the world's workers of the man who was almost solely responsible for the transformation of the steam engine from an expensive and relatively ineffective pumping apparatus, to the great central power that has ever since moved the major part of the world's machinery.

No other invention within historical times has had so important an influence upon the production of property—which is the gage of the world's work—as this invention of the steam engine. We have followed the history of that invention in some detail, because of its supreme importance. To the reader who was not previously familiar with that history it may seem surprizing that after a lapse of a little over a century one name and one alone should be popularly remembered in connection with the invention; whereas in point of fact various workers had a share in the achievement, and the man whose name is remembered was among the last to enter the field. We have seen that the steam engine existed as a practical working machine several decades before Watt made his first invention; and that what Watt really accomplished was merely the perfecting of an apparatus which already had attained a considerable measure of efficiency.

There would seem, then to be a certain lack of justice in ascribing supreme importance to Watt in connection with the steam engine. Yet this measure of injustice we shall find, as we examine the history of various inventions, to be meted always by posterity in determining the status of the men whom it is pleased to honor. One practical rule, and one only, has always determined to whom the chief share of glory shall be ascribed in connection with any useful invention.

The question is never asked as to who was the originator of the idea, or who made the first tentative efforts toward its utilization—or, if asked by the historical searcher, it is ignored by the generality of mankind.

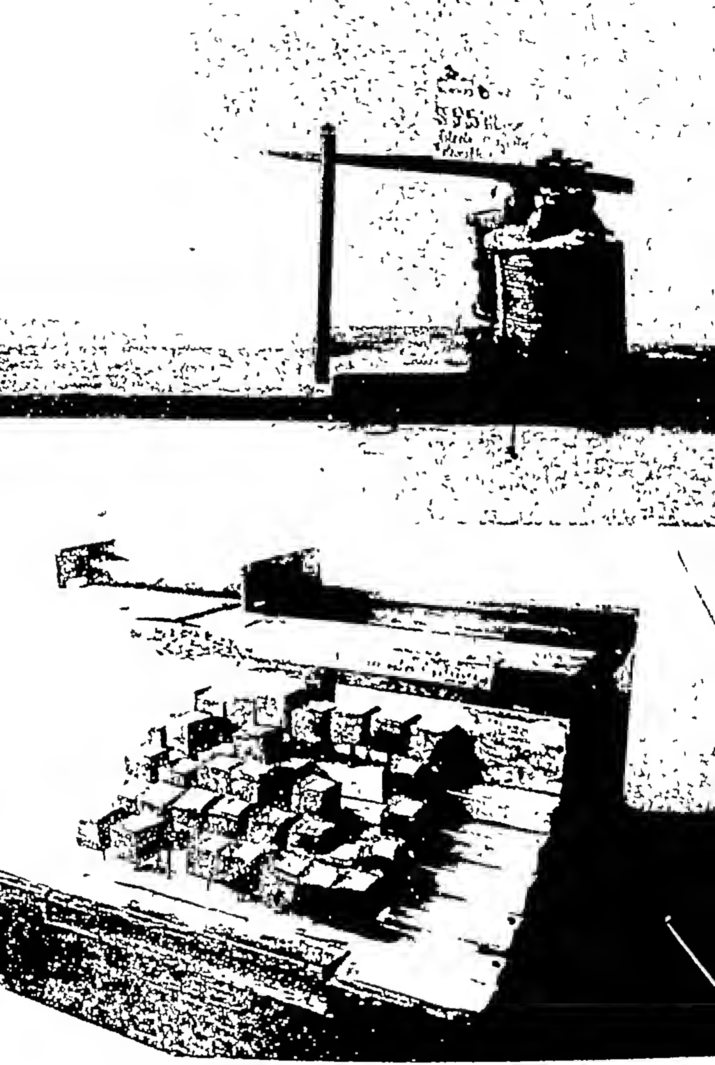
So far as the public verdict, which in the last resort determines fame, is concerned, the one question is, Who perfected the apparatus so that it came to have general practical utility? It may be, and indeed it usually is the case, that the man who first accomplished the final elaboration of the idea made but a comparatively slight advance upon his predecessors; the early workers produced a machine that was *almost* a success; only some little flaw remained in their plans. Then came the perfecter, who hit upon a device that would correct this last defect—and at last the mechanism, which hitherto had been only a curiosity, became a practical working machine.

In the case of the steam engine, it might be said that even a smaller feat than this remained to be accomplished when Watt came upon the scene; since the Newcomen engine was actually a practical working apparatus. But the all-essential thing to remember is that this Newcomen engine was used for a single purpose. It supplied power for pumping water, and for nothing else. Neither did it have possibilities much beyond this, until the all-essential modification was suggested by Watt, of exhausting its steam into exterior space.

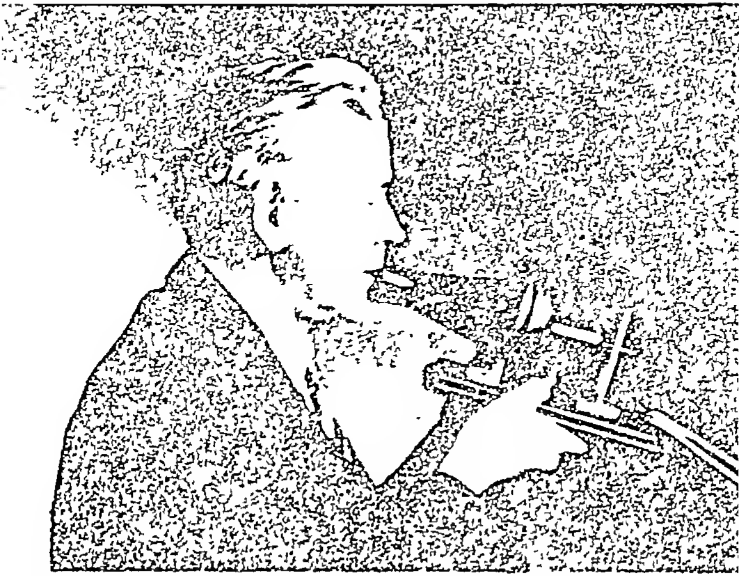
This modification is in one sense a mere detail, yet it illustrates once more the force of Michelangelo's famous declaration that trifles make perfect; for when once it was tested, the whole practical character of the steam engine was changed. From a wasteful consumer of fuel, capable of running a pump at great expense, it became at once a relatively economical user of energy, capable of performing almost any manner of work.

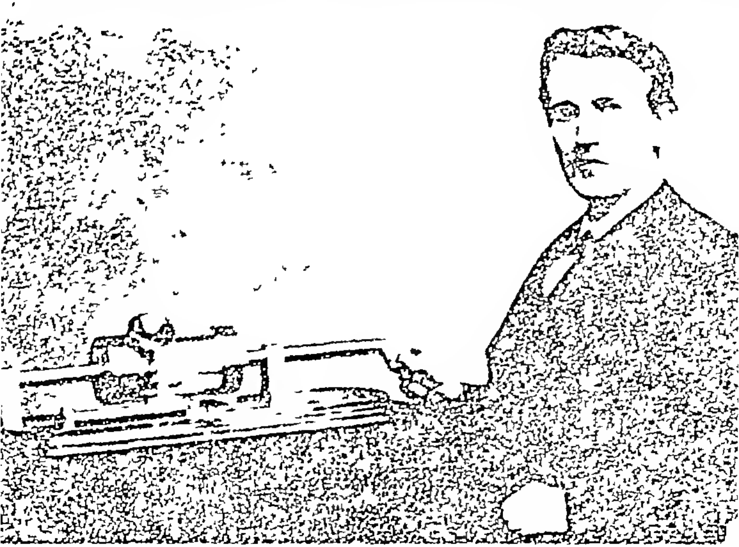
Needless to say, its possibilities in this direction were not immediately realized in theory or in practise; yet the conquest that it made of almost the entire field of labor resulted in the most rapid transformation of industrial conditions that the world has ever experienced. After all, then, there is but little injustice in that public verdict which remembers James Watt as the inventor, rather than as the mere perfecter, of the steam engine.

ELIAS HOWE AND HIS SEWING MACHINE

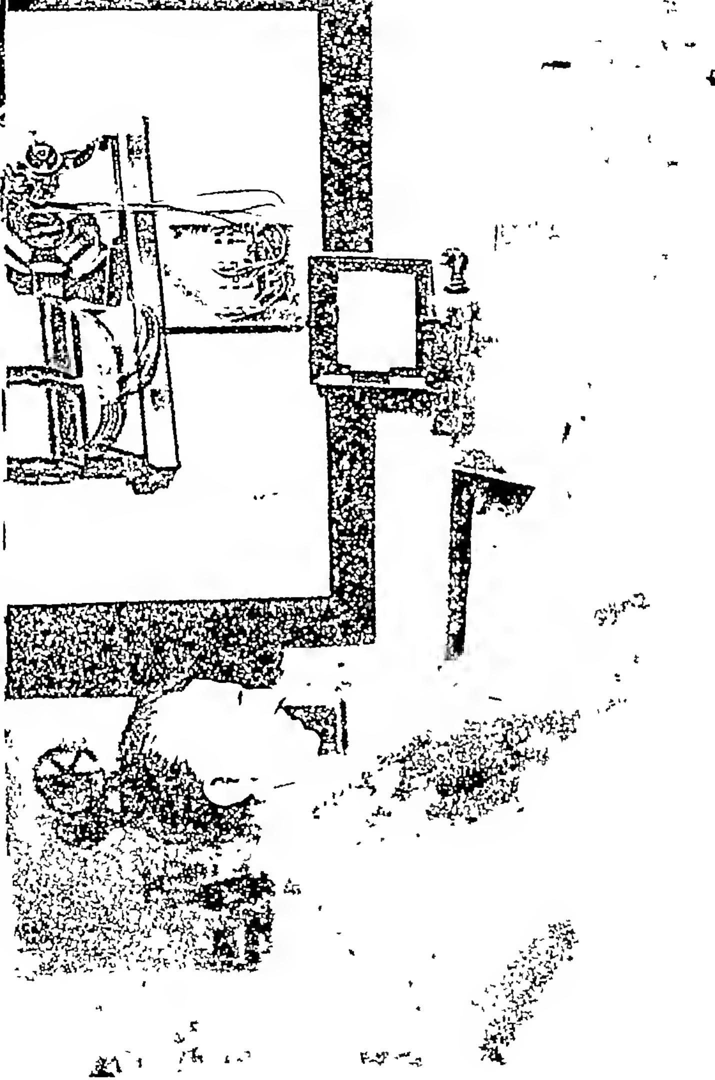


MORSE TELEGRAPH AND FIRST TYPEWRITER

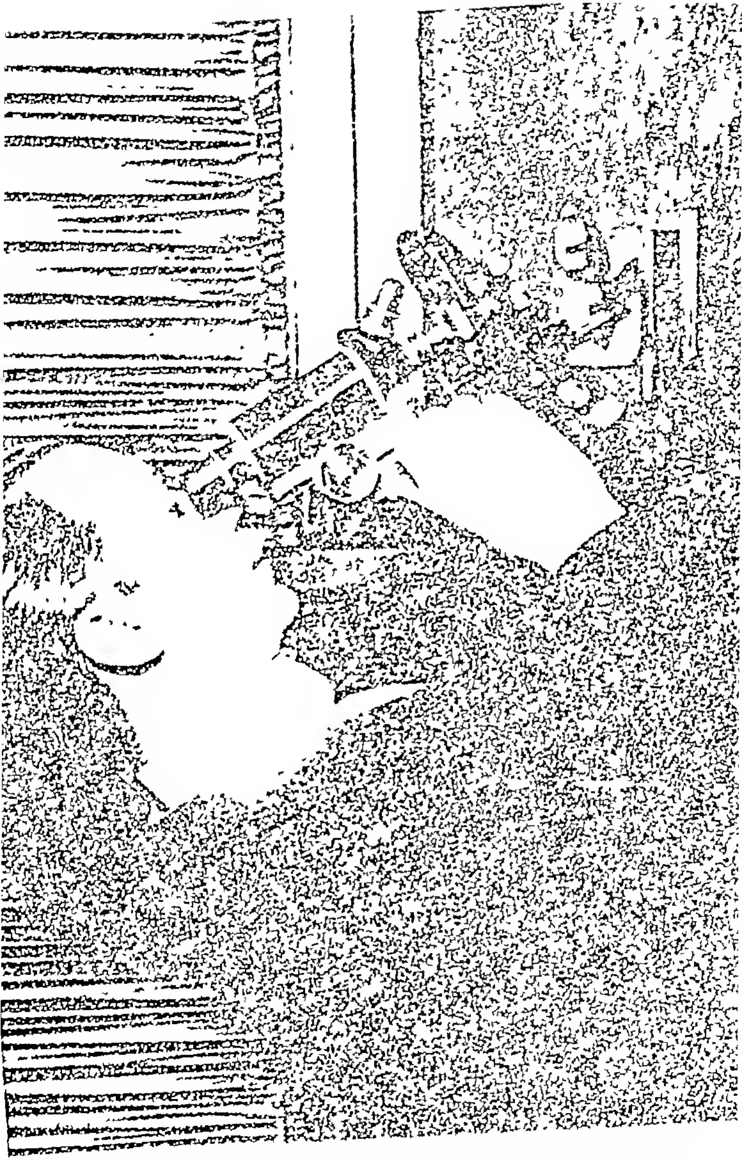


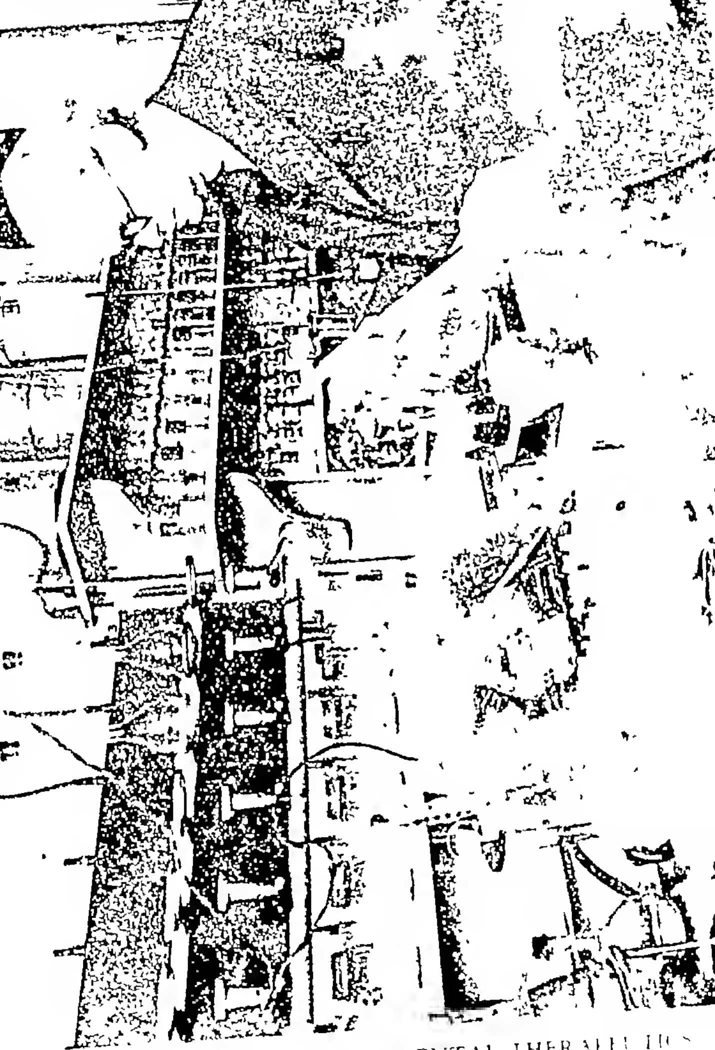


FIRST DAGUERREOTYPE PORTRAIT —
MISS DRAPER 57 YEARS LATER



NICOLA TESLA





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